GROWTH OF YOUNG 'HAMLIN' ORANGE TREES AS INFLUENCED BY MICROSPRINKLER IRRIGATION, FERTILIZATION, AND NURSERY TREE TYPE

By

THOMAS E. MARLER

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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Thomas E. Marler

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Young tree care is a costly and important part of any citrus production program. Irrigation, fertilization, and nursery stock characteristics have a major influence on the success of a young tree care program. Therefore field experiments were conducted to study the effects of various microsprinkler irrigation and fertilization rates and nursery tree types on growth and development of young 'Hamlin' orange [*Citrus sinensis* (L.) Osb.] trees.

Three experiments were conducted to determine the effects of scheduling microsprinkler irrigations at 20 (high frequency), 45 (moderate frequency), and 65% (low frequency) available soil water depletion on one season's canopy and root growth and leaf gas exchange. Canopy and root growth were similar for high and moderate treatments in 2 out of 3 years, but were reduced by the low treatment, even though the moderate received about 50% less water than the high treatment. Reduced shoot number and delayed

initiation of late growth flushes sometimes occurred with moderate and low treatments, and may have been related to decreases in CO_2 assimilation in spring and early summer. Root concentrations were greatest between 10 and 30 cm depths, and >90% of the root dry weight was within 80 cm of the trunk.

Two studies with various fertilizer rates and two studies with controlled-release fertilizer sources were conducted to determine the influence of fertilizer rate and source on growth. Growth was comparable over one season using 0.07-0.09, 0.14-0.18 (recommended), and 0.22-0.27 kg N/tree/season, implying that adequate rates may sometimes be lower than recommended. In addition, application of standard fertilizers (4-5X/season) compared with controlled-release fertilizers (2X) at the same seasonal rates resulted in similar growth over 2 seasons, suggesting that controlled-release sources may sometimes be used as alternatives to standard sources.

Commercial bare-rooted, field-grown nursery trees and containerized, greenhouse-grown trees were used in three experiments to compare establishment and initial growth in the field. Bare-rooted trees remained larger than containerized trees through 2 seasons and initial growth of container-grown trees was highly variable. Removal of medium prior to planting container-grown trees improved tree growth in one of two experiments.

CHAPTER I

INTRODUCTION

Citrus plantings in Florida decreased by more than 75,000 hectares between 1984 and 1986 (Division Plant Industry, 1986), more than any other 2-year period since the beginning of the Citrus Tree Census Survey in 1966. This decrease was largely attributable to the series of freezes since 1982; however, blight, tristeza, and urbanization have also contributed to the reduction in land area planted to citrus. Growers estimated in 1983-1984 that 6.1% of their young trees died each year (Jackson et al., 1986). Estimates of the number of trees being planted annually in the mid-1980s range from greater than 3 million (Division Plant Industry, 1986) to 6-10 million (Jackson et al., 1986).

Muraro (personal communication, Citrus Research and Education Center, Lake Alfred) estimates that more than $20 is required to maintain a tree in a solid-set planting for the first 4 years in the flatwood areas, while $24 to $40 per tree is required for resets, depending on number of resets per hectare. Consequently, young tree care costs are immense on an industry-wide basis. More efficient management practices for young citrus trees are important in the success of any profitable citrus production venture due to the increased need for cost containment in the Florida citrus industry.

Vital to the improvement of field management practices is the understanding of how these practices influence the growth and physiology of young citrus trees.

Irrigation practices for mature Florida citrus trees are based on many years of field research, however, information on water requirements of young citrus trees, irrigation scheduling, and tree response has not been reported with micro irrigation under field conditions in Florida. Objectives of the first part of this research were to investigate the effects of microsprinkler irrigation scheduling based on soil water depletion on canopy and root growth of young citrus trees. In addition, the influence of soil water deficit on gas exchange processes of young citrus trees was studied. Separate experiments were designed to investigate the effect of microsprinkler irrigation spray pattern on growth of trees during the second season in the field.

Fertilization practices for mature Florida citrus are well-defined and based on years of production records, but fewer studies have been made on fertilization of young citrus trees. Previous studies suggest that under many conditions fertilizer rates for young trees are excessive. Use of controlled-release fertilizers may reduce nitrogen losses and fertilizer costs by decreasing the number of yearly fertilizer applications, resulting in reduced labor and equipment costs. Objectives of the second portion of this research were to compare growth of young citrus trees using standard fertilizer applied at recommended seasonal rates and controlled-release fertilizer applied fewer times per season than the standard source. A second set of experiments was designed to determine if

recommended seasonal fertilization rates could be reduced without a reduction in young citrus tree growth.

Florida nurserymen have been producing bare-rooted citrus trees in field nurseries for many years, however, recently many citrus trees have been produced in containers in greenhouses. While opinions vary concerning post-plant growth and survival rates of container-grown and field-grown trees, there have been no replicated, controlled comparisons of these two nursery tree types under Florida conditions. The purpose of the third part of this research was to compare establishment and post-plant canopy and root growth of 1)containerized, greenhouse-grown and 2)bare-rooted, field-grown citrus trees. Further experiments were designed to determine the effect of the removal of potting medium prior to planting on root and canopy growth of container-grown citrus trees.

Results from these experiments may be useful in improving management programs for young citrus trees by reducing water and fertilizer costs and may lead to further research on optimizing growth and development of young citrus trees in Florida.

CHAPTER II

REVIEW OF THE LITERATURE

Citrus tree growth and productivity is influenced by many environmental conditions and cultural factors. Adequate soil moisture and nutrient levels are two important factors necessary for optimum tree growth. Moreover, initial growth and development of newly-planted trees may be influenced by the nursery conditions under which they were produced. Understanding the influence of nursery and field management decisions on growth and physiological processes of young citrus trees is important to maximize early productivity.

Vegetative Growth and Development of Citrus

Citrus shoot growth is cyclic with two to five flushes per season, depending on climate (Cooper et al., 1969; Mendel, 1969). Environmental conditions may alter both number and timing of growth flushes. Following cessation of shoot elongation the terminal bud normally aborts and abscises (Schroeder, 1951). Duration of flush growth is largely dependent upon climate, as cooler spring temperatures result in longer periods of growth (Cooper et al., 1963). Both the spring (Cooper et al., 1963) and summer (Krishnamurthi et al., 1960) flushes have been reported to occur over the longest time interval.

Shoot growth is mainly dependent on stored substrates in citrus (Sinclair, 1984). Available reserves influence shoot length and number of leaves per shoot (Van Noort, 1969). The spring flush normally has more shoots than other flushes, but average shoot length is shorter (Mendel, 1969; Krishnamurthi et al., 1960). Later flushes have fewer buds breaking and longer average shoot length, thicker shoots, and larger leaves (Reuther, 1973; Mendel, 1969). A large proportion of spring shoots do not continue growing during subsequent flushes (Sauer, 1951). Summer (Mendel, 1969) and spring (Crider, 1927; Krishnamurthi et al., 1960; Syvertsen et al., 1981) flushes have each been attributed with having more total growth than the other growth flushes.

In the spring root growth usually occurs after shoot growth (Crider, 1927; Cooper et al., 1963; Bevington, 1983; Hatton, 1949; Krishnamurthi et al., 1960; Reed & McDougal, 1937), except in one case where shoot growth occurred first (Waynick & Walker, 1930). This occurs possibly because soil temperatures are lower than air temperatures in early spring (Krishnamurthi et al., 1960).

Shoot and root growth flushes tend to alternate. During periods of very active shoot growth the roots are inactive or nearly so (Crider, 1927; Bevington, 1983; Bevington & Castle, 1985; Krishnamurthi et al., 1960; Reed & McDougal, 1937). Mendel (1969) suggests that increases and decreases in the amount of growth inhibiting substances may govern the cycles. Trunk growth may be cyclical, coinciding generally with root growth (Krishnamurthi et al., 1960), or continuous throughout the growing season (Cooper et al., 1963).

Alternating periods of root and shoot growth and extent of growth are greatly influenced by the environment. Shoot growth is reduced below 12.5-13.0° C and above 33-39° C, with optimum growth occurring between 23-33° C (Mendel, 1969; Reuther, 1973). Root growth is maximum at soil temperatures of 25-26° C (Reuther, 1973), and limited below 13 or above 36° C (Castle, 1978). Increases in soil temperature increase translocation of assimilates to roots (Vinokur, 1957).

Daylength influences shoot growth of most citrus. While some citrus is non-responsive to daylength (Warner et al., 1979), many rootstocks and scions produce more and longer shoots in longer daylengths (Lenz, 1969; Reuther, 1973; Warner et al., 1979).

The root and shoot relationship is measured many times as a ratio of fresh or dry weight of shoot and root systems. Mature citrus trees in California had shoot:root ratios of ca. 3.5 (Cameron, 1939; Cameron & Compton, 1945) and in Florida of 2.2 (Castle, 1978). This ratio varies within a species with age and environmental or cultural conditions. Some factors that influence shoot:root ratio of a number of crops are soil moisture levels (Harris, 1914; Hilgeman & Sharp, 1970; Hsiao & Acevedo, 1974; Kramer, 1983; Kriedeman & Barrs, 1981; Levy et al., 1983; Menzel et al., 1986; Rodgers, 1939; Tinus & Owston, 1984), mineral nutrition, especially nitrogen (Brouwer, 1962; Harris, 1914; Russel, 1977; Turner, 1922), light intensity (Russell, 1977), and root restriction (Hameed et al., 1987).

Water Relations

Growth Responses to Water Deficits

Most aspects of plant metabolism are affected by tissue water relations, but turgor-dependent processes, such as cellular expansion, are especially sensitive. Water deficits reduce cell expansion and division, organ growth, or whole plant growth (Hagan et al., 1959; Hsiao, 1973). Studies with forest trees indicate that water deficits during bud formation can have as much influence on shoot length as stress during shoot expansion (Kozlowski, 1983; Doley, 1981). In addition to reduced production of new leaf area during periods of water deficits, abscission of older existing leaves may increase the loss in leaf area (Marsh, 1973; Kriedemann & Barrs, 1981).

Soil water deficits may result in cessation of growth of a flush or prolong the period of quiescence between flushes in citrus (Cooper et al., 1969; Mendel, 1969). Ford (1964) stated that the alternations between root and shoot growth may become less pronounced during periods of drought.

Growth reduction in response to water stress may be immediately followed by an increased growth rate upon relief of stress. This has been shown with corn (Acevedo et al., 1971; Hsiao et al., 1970), soybean (Bunce, 1977), tomato (Gates, 1955), pine (Miller, 1965), barley and rye (Williams & Shapter, 1955) under short term stress. Similarly, early season moisture stress suppressed dogwood shoot growth initially, but stimulated late season growth following regular irrigation (Williams et al., 1987).

Root growth is likewise affected by moisture stress, although to a lesser degree than shoot growth. Reduced meristematic activity and root elongation as well as reduced water and nutrient uptake due to suberization occur in response to water deficits in most crops (Slatyer, 1969). Working with wheat, Cole and Alston (1974) state that root volume or weight are generally more affected by water deficits than root length. The rate of suberization may exceed that of elongation during periods of water deficits, substantially reducing the non-suberized root area (Kaufmann, 1968; Kramer, 1950; Turner & Kramer, 1980). Periods of water deficits have reduced citrus root conductivity (Levy et al., 1983; Ramos & Kaufmann, 1979) and root elongation (Bevington, 1983; Bevington & Castle, 1985; Marsh, 1973). Water deficits may result in development of long roots with restricted branching in citrus (Castle, 1978). Resumption of root growth following rain or irrigation typically occurs with most crops (Kozlowski, 1983), however, pine roots reportedly matured toward the tip during water deficits and became inactive (Kaufmann, 1968; Lesham, 1965).

Total root growth and distribution of citrus trees are often altered by irrigation practices. Infrequent irrigation increased root density or the proportion of total roots deep in the soil profile when compared to frequent irrigation (Cahoon et al., 1961; Cahoon et al., 1964; Hilgeman & Sharp, 1970; Marsh, 1973; Ruggiero & Andiloro, 1985). Partial root zone irrigation in an arid environment results in an increase in root growth in the wetted soil volume (Bielorai, 1977, 1982; Bielorai et al., 1981; Cohen et al., 1987; Rodney et al., 1977). Conversely, high root concentrations

within the wetted areas do not occur in regions of abundant rainfall (Koo, 1980).

Gas Exchange Responses to Water Deficits

Water influences plant growth and development through its effect on biochemical and physiological processes, including gas exchange. It is clearly established that stomatal conductance generally declines under conditions of water deficit. This stomatal response has been considered to be a feedback response to leaf water status, involving a reduction of leaf water potential, turgor potential, or relative water content to a critical point, at which time the stomata begin to close (Begg & Turner, 1976; Hsiao, 1973; Raschke, 1975; Turner, 1979). However, correlations of bulk leaf water status and stomatal conductance are typically weak, and the relationship is not consistent, but is dependent on developmental conditions. Numerous recent reports with a variety of crops show that decreases in stomatal conductance resulting from soil moisture depletion are not closely correlated with changes in bulk leaf water status (Bates & Hall, 1981; Bennett et al., 1987; Black et al., 1985; Blackman & Davies, 1985b; Cock et al., 1985; Gollan et al., 1985; Lorenzo-Minguez et al., 1985; Osonubi, 1985; Turner et al., 1985). Furthermore, stomata respond directly to epidermal water relations and are only indirectly related to bulk leaf water relations (Edwards & Meidner, 1978). The pressure probe has recently been used to directly measure turgor of individual cells (Shackel & Brinckmann, 1985; Frensch & Schulze, 1987) and it is now evident that large cell turgor gradients may exist between mesophyll

and epidermis, illustrating the problems associated with relating stomatal conductance with bulk leaf water status.

Stronger correlations of stomatal conductance to soil moisture status than to leaf water status (Bates & Hall, 1981, 1982; Blackman & Davies 1985b; Gollan et al., 1985; Gollan et al., 1986; Jones et al., 1983; Osonubi, 1985; Turner et al., 1985) suggest that soil water deficits may influence stomata in a manner independent of shoot water relations. The most clear evidence of this comes from stomatal closure in response to soil water deficits, in spite of maintenance of leaf turgor by partial root zone irrigation (Blackman & Davies, 1985 a,b) or by pressurizing the root system (Gollan et al., 1986). In these cases, stomata responded directly to a signal from roots under soil water deficits. An interruption in cytokinin supply has been proposed as this message (Blackman & Davies 1985 a,b; Davies et al., 1986). It has been known for two decades (Itai & Vaadia, 1965) that soil water deficits affect concentrations of growth substances in roots and shoots. The well-known involvement of abscisic acid (ABA) in stomatal action (Davies et al., 1981) and the interaction of this ABA effect with other phytohormones (Blackman & Davies, 1985 a,b; Cox et al., 1985; Snaith & Mansfield, 1982) lend support to the suggestions that plant growth substances play a role in the stomatal response to soil water deficits. However, stomatal closure of some plants is not related to leaf ABA levels (Davies & Lakso, 1978; Raschke et al., 1976).

The discovery that stomata respond directly to humidity (Lange et al., 1971) in a feed-forward manner is well-documented in many plants. Feedforward responses are important in enabling a plant to

restrict excessive water loss before developing a severe water deficit. Sharkey (1984) has shown that high transpiration may result in reduced photosynthetic capacity in a manner similar to soil water deficits, and suggests that stomatal responses to humidity may guard against this reduction in photosynthetic capacity. Stomatal responses to humidity can greatly confuse interpretation of stomatal responses to soil water deficits. This stomatal sensitivity to humidity or vapor pressure deficit (VPD) is well-documented in citrus (Camacho-B., 1977; Camacho-B. et al., 1974; Fereres et al., 1979; Hall et al., 1975; Kaufmann, 1977; Kaufmann & Levy, 1976; Khairi & Hall, 1976b; Kriedemann & Barrs, 1981; Levy, 1980; Syvertsen, 1982) and is important in maintaining favorable leaf water relations under arid environments. Well-watered citrus trees in environments of drastically different evaporative demand have been shown to have nearly equal transpiration and equal or increased leaf water potential in arid environments due to VPD-induced partial stomatal closure (Kaufmann, 1977; Levy, 1980; Levy & Syvertsen, 1981). Hilgeman (1966) reported nearly equal transpiration but greater leaf water deficits of citrus in Arizona compared to Florida. Annual evapotranspiration values for mature citrus in different environments are quite similar, ranging from 1.07 to 1.21 m in Florida (Koo, 1963; Rogers et al., 1983; Rogers & Bartholic, 1975; Reitz et al., 1978; Gerber et al., 1973), 0.91 to 1.14 m in Texas (Weigand & Swanson, 1982a), and 0.80 to 1.47 m in Arizona (Hilgeman & Sharp, 1970; Hilgeman et al., 1969; Hoffman et al., 1982).

The literature concerning soil water deficit effects on photosynthesis is extensive and has been reviewed by many [e.g. Boyer (1976), Hsiao (1973), Lawlor (1979), Slatyer (1967)]. Early research suggested that stomatal conductance and CO_2 assimilation are closely correlated for some species, and led to conclusions that CO_2 assimilation was reduced by soil water deficits through stomatal closure. However, water stress also impairs non-stomatal factors which may be causal, yet closely correlated with stomatal conductance. The correlation could result from a concommitant yet independent effect of water deficits on stomatal and non-stomatal processes, or from a direct reduction in mesophyll photosynthetic capacity, followed by stomatal closure in response to reduced CO_2 assimilation (Farquhar & Sharkey, 1982; Redshaw & Meidner, 1972; Wong et al., 1979).

Non-stomatal limitations on photosynthesis are well-documented. Residual conductance to CO_2 is reduced by water stress in many plants (Brown & Simmons, 1979; Bunce, 1977; Collatz, 1977; Mederski et al., 1975; O'Toole et al., 1976; Pearcy, 1983; Pellegrino et al., 1987; Radin & Ackerson, 1981). Stress-induced reduction of photochemical activity has been shown by using isolated chloroplasts and artificial electron acceptors or with measurements on fluorescence (Boyer, 1976; Boyer & Bowen, 1970; Genty et al., 1987; Keck & Boyer, 1974; Nir & Poljakoff-Mayber, 1967; Sharkey & Badger, 1982; Von Caemmerer & Farquhar, 1981). Reduced carboxylation capacity in response to stress has also been reported due to decreases in activity of ribulose bisphosphate carboxylase-oxygenase, carbonic anhydrase, phosphoenol pyruvate carboxylase,

fructose-1,6-bisphosphatase, or sedoheptulose-1,7-bisphosphatase (Berkowitz & Gibbs, 1982; Boag & Portis, 1984; Huffaker et al., 1970; Jones, 1973; O'Toole et al., 1976). In situations where intercellular CO_2 concentration is unchanged or higher in stressed than in control plants, reduced stomatal conductance of stressed plants is of little importance in photosynthetic reduction (Briggs et al., 1986; Farquhar et al., 1980; Radin & Ackerson, 1981; Wong et al., 1979).

Inhibition of leaf growth by water deficits may contribute to a whole plant reductions in photosynthesis. Water deficits may reduce the rate of leaf initiation (Husain & Aspinall, 1970) as well as foliar expansion (Hagan et al., 1959; Hsiao, 1973). Additional loss of leaf area through abscission of existing leaves may also result from water deficits. Stress-induced foliar abscission in citrus normally occurs at a secondary abscission zone between the leaf blade and petiole (Schneider, 1968). These effects may be quite damaging, since recovery does not occur until new growth replaces the lost photosynthetic surface (Hsiao, 1973).

Effects of water deficits on photosynthesis are certainly not fully understood. The fact that such diverse mechanisms of action are discussed in the literature is not surprising and all mechanisms could be applicable under certain situations.

Water deficit effects on gas exchange of citrus has received fairly limited attention. Hilgeman (1977) stated stomatal closure of mature citrus in Arizona occurs at progressively earlier times in the day as soil water is depleted over several weeks. Irrigated and nonirrigated mature sweet orange trees in Italy began days with

similar stomatal conductances, but conductance of nonirrigated trees declined steadily throughout the day, while that of irrigated trees increased to peak around midday before declining (Ruggiero & Andiloro, 1985). Similarly, leaf conductance of severely-stressed mature sweet orange trees increased slightly until mid-morning before declining steadily throughout the day, while conductance of irrigated trees increased rapidly until mid-morning and did not decline any until mid-afternoon (Cohen & Cohen, 1983). Hilgeman et al. (1969) reported increased transpiration of mature sweet orange trees in Arizona at a soil matric potential of -29 kPa compared to -79 kPa, especially during the middle part of the day. Koo (1953) reported citrus tree transpiration in Florida was unchanged at soil moisture levels between field capacity and depletion of two-thirds of the readily available water. A reduction in transpiration or stomatal conductance by soil water deficits has been reported under many conditions (Bielorai & Mendel, 1969; Brakke et al., 1986; Cohen & Cohen, 1983; Hilgeman, 1977; Kaufmann & Levy, 1976; Koo, 1953; Kriedeman, 1971; Ruggiero & Andiloro, 1985; Thompson et al., 1968; Zekri, 1984). Only controlled conditions utilizing containerized plants have been used to illustrate a reduction of citrus photosynthesis by soil water deficits (Bielorai & Mendel, 1969; Brakke et al., 1986; Kriedemann, 1968, 1971; Ono & Hirose, 1984; Thompson et al., 1968). Bielorai & Mendel (1969) reported that sweet lime and rough lemon photosynthesis was reduced more than transpiration with soil water deficits, while Kriedemann (1971) reported a greater reduction of transpiration with sweet orange.

Irrigation of Mature Citrus

Irrigation in Florida

Although Florida's climate is characterized by an average annual rainfall of 120-150 cm, the rainfall is distributed in an irregular pattern. Consequently, periods of minimal and infrequent rainfall result in unfavorable soil moisture conditions for optimum citrus growth and production. Periods of drought combined with the low water-holding characteristics of most Florida soils create favorable conditions for the use of irrigation to obtain maximum production.

Many early studies presented differing results concerning the need to irrigate mature citrus trees (DeBusk, 1928, 1933; Hoard, 1908; Koo & Sites, 1955; Savage, 1951, 1952; Sites et al., 1951; Staebner, 1919; Stanley, 1913, 1914, 1916; Stevens, 1909; Williams, 1909; Young, 1948; Ziegler, 1955b). Many of these reports were based on observations and correlations between rainfall or soil moisture content and tree response, while some were actual irrigation experiments. Responses to irrigation and opinions on its cost effectiveness varied widely. Ziegler (1955b) stated that irrigation was needed in Florida only in years of light spring rainfall, and was not essential every year, and suggested the use of temporary wilt or "anticipated tree wilt" combined with records of rainfall for practical irrigation timing (Ziegler, 1955a).

Results of a 3-year study were published in 1963 indicating that irrigation based on soil moisture depletion increased yields for a variety of scions on rough lemon rootstock (Koo, 1963). Recommendations were to irrigate from January to June based on

one-third soil moisture depletion, and from July to December based on two-thirds depletion. Since that time irrigation has ranked high among requirements for maximum production of Florida citrus, even in years of high rainfall. Thus, irrigation has been used in Florida to increase yields of many cultivars on different rootstocks (Koo, 1963, 1969, 1975, 1979, 1985; Koo & Hurner, 1969; Koo & McCornack, 1965; Koo & Sites, 1955; Koo et al., 1974; Reese & Koo, 1976). Likewise, irrigation increases vegetative growth of mature citrus trees under Florida conditions (Koo, 1963, 1969, 1979, 1985; Koo & Hurner, 1969; Sites et al., 1951; Zekri, 1984). Increases in citrus yield due to irrigation may result from an increase in canopy volume (Koo, 1969; Koo & Hurner, 1969; Levy et al., 1978). Recommendations similar to Koo's (1963) concerning more frequent irrigation during the spring than other parts of the year are reported for other citrus growing regions (Hilgeman, 1956; Hilgeman & Sharp, 1970; Mantell, 1977; Weigand & Swanson, 1982a).

Micro Irrigation of Mature Citrus

Micro irrigation systems, which direct water to only a portion of the soil volume, have received widespread use in citrus culture around the world. Yields of navel oranges were comparable using trickle, basin, and dragline sprinklers in South Africa, with ca. 50% savings of applied water for the trickle systems over the other systems (Bester et al., 1974). Similarly, water savings of 30% were possible while using trickle instead of flood irrigation on grapefruit in Arizona (Roth et al., 1981). Irrigating oranges with trickle or basin systems in Arizona reduced water application by greater than 90% when compared with border or high volume sprinkler

methods (Roth et al., 1974). Increased tree growth and reduced weed control problems also resulted from the use of trickle and basin irrigation. Drip irrigation increased yields and fruit size of sweet oranges by 30% over flood irrigation in Spain (Legaz et al., 1981). Similar comparisons of trickle systems and conventional systems with mature citrus are numerous (Alijbury et al., 1974; Cole & Till, 1974; Leyden, 1975b; Rathwell & Leyden, 1976; Yagev & Choresh, 1974) and include those cited in the next discussion.

Irrigation studies frequently use several types of systems or emitters to apply water to variable percentages of soil surface. Bielorai (1977, 1978, 1982) reported similar grapefruit yields and tree growth resulted in Israel from wetting 30-40 as compared to 70% of the soil surface. Similarly, irrigation of 35, 70, and 90% of the soil surface for oranges resulted in increased or comparable yields with the smaller wetted areas (Bielorai et al., 1981). These results involved data from only the first 3 years following a reduction in wetted soil volume. Following this period, however, yields of the 90% wetting treatment were greater than for the other treatments (Cohen et al., 1985). Another comparison of orange performance in Israel showed a reduction in growth rate and yield with partial compared to full wetting (Moreshet et al., 1983). Other responses included reduced water uptake and tree hydraulic conductance due to reduced wetted soil volume (Cohen et al., 1985, 1987). Koo and Tucker (1974) recommended in Florida that systems be designed to wet 60% of the citrus root volume. However, irrigating high-density oranges at 15-25%, 30-40%, and 70-78% of the under-tree area showed that yield increased with increasing coverage (Koo,

1978). Grapefruit irrigated at 14, 64, and 100% coverage of under-tree area also responded with increased yield and growth with increasing coverage (Koo, 1985). Irrigation at 19, 88, and 100% of under-tree area gave similar results (Zekri, 1984). Five to 10%, and 28 to 51% coverage of the under-tree area increased yield of oranges 41-44 and 65%, respectively, over nonirrigated controls in Florida (Smajstrla & Koo, 1984, 1985).

Fertilization

Uptake and Function of Minerals

Plants require adequate supplies of essential elements for optimum growth and development. These elements affect plant growth through their involvement in physiological and biochemical processes. The amount required by plants, form that is absorbed, and function vary considerably among the essential elements.

Agricultural soils are more commonly deficient in nitrogen (N) than any other element. Nitrogen is an essential component of amino acids, chlorophyll, and many other organic materials, and is involved in many enzymic processes. Various forms of N are absorbed by roots, but nitrate and ammonium are the major forms. Preferential absorption of ammonium (Wallace, 1954; Wallace & Mueller, 1957) or nitrate (Hilgeman, 1941) has been suggested in citrus. Several studies have provided estimates of the partitioning of N throughout the citrus plant. Leaves contained 31% of the N in a mature orange tree in Florida; with fruit, small roots, branches, large root, and the trunk containing 27, 21, 13, 5, and 3%, respectively (Smith, 1963). Cameron and Compton (1945) presented data from California suggesting that leaves contain 40-50%; twigs

and shoots, 10%; trunk and branches, 20-30%; and roots, 15-20% of the total N. In contrast, leaves contained greater than 60% of the total N in 3.5 year old orange trees (Cameron & Applemen, 1933). Averaged over the entire season, N content was 1.86% of the total tree dry weight.

Absorption and function of the remaining essential elements are covered in detail by Clarkson and Hanson (1980) and Mengel and Kirkby (1982) and are briefly outlined here. Carbon, hydrogen, oxygen, and sulfur have metabolic functions similar to N, in that they are structural components of essential plant compounds and are involved in enzymic processes. Sulfur is absorbed from the soil as sulfate, or from the atmosphere as sulfur dioxide. Carbon, hydrogen, and oxygen are absorbed in gaseous forms from the atmosphere. Phosphorus, boron, and silicon are involved in esterification with alcohol groups in plants, and are absorbed as phosphates, borate or boric acid, and silicate, respectively. Potassium, sodium, magnesium, calcium, manganese, iron, chlorine, copper, zinc, and molybdenum are absorbed by plants in the form of ions or chelates. Their metabolic functions are numerous, and range from controlling osmotic and electro-potentials and membrane permeability to enzyme activation.

Fertilization of Mature Citrus in Florida

Plant growth and yield increase with added fertilizer up to a critical level, after which no significant increase occurs. As this level of maximum production is approached, the increase in response for a specific rate increase becomes less and less. Citrus tree responses to fertilization do not increase indefinitely with

increased fertilization rates, nor do trees accumulate excessive amounts when minerals are present in large quantities (Koo et al., 1984; Sites et al., 1953; Sites et al., 1961; Smith & Rasmussen, 1961; Stewart et al., 1961; Wallace et al., 1952). Optimum fertilization rates depend not only on response to increased fertilizer application, but on fertilizer and fruit prices as well.

Current recommendations for fertilizing mature citrus groves in Florida (Koo et al., 1984) are based on many years of controlled experiments. Mature citrus trees require from 100 to 340 kg N/ha/year to maintain optimum production, however, rates above 225 kg/ha are rarely justifiable in terms of yield increase for most citrus cultivars.

Many field experiments have been conducted to determine the optimum number and timing of fertilizer applications and the effect of elemental sources on mature citrus trees. Results generally agree that frequency or timing are of far less importance than fertilizer rate (Calvert & Reitz, 1964; Reitz, 1956; Reuther & Smith, 1954; Sites et al., 1953, 1961; Smith, 1970). One to two applications per year are adequate when recommended rates are used. Nutrient source is also of little consequence in yield responses of mature citrus trees (Camp, 1943; Leonard et al., 1961; Reitz, 1956; Reitz & Koo, 1959; Sites, 1949; Sites et al., 1953; Smith, 1970; Stewart et al., 1961).

Nitrogen Losses

Applied N may be lost from the soil in many ways. Ammonium salts and urea may be lost by volatilization of ammonia, especially on calcareous soils (Volk, 1959; Wahhab et al., 1957).

Nitrification, the bacterial oxidation of ammonia to nitrate, can lead to increased losses of N from the root zone by leaching of nitrate. Reduction of nitrate to volatile forms of N is carried out by many species of bacteria in the soil. This process (denitrification) is promoted by high soil moisture and temperatures (Mengel & Kirkby, 1982).

About a third of the applied N was lost through leaching in a newly-developed Florida citrus grove (Calvert, 1975; Calvert & Phung, 1971). An average of 50 kg N/ha may be lost annually through leaching in Florida groves (Barnette, 1936). Annual leaching losses from some southern California citrus orchards have been estimated at about 67 kg N/ha (Bingham et al., 1971), which is equivalent to about 45% of the applied N. Wallace et al. (1952) estimated a 15% recovery of applied N by citrus trees in southern California. Similarly, annual losses of up to 67 kg/ha have been attributed to volatilization (Chapman, 1951; Chapman et al., 1949).

Controlled-Release Fertilizer Sources

Controlled-release fertilizer sources that are N carriers can be used to substantially reduce losses of applied N (Maynard & Lorenz, 1979; Oertli, 1980). Some benefits from using controlled-release fertilizers are reduced losses of applied N through leaching, denitrification, or volatilization; the possibility of less frequent applications; and increased efficiency in use of materials (Allen & Mays, 1974; Oertli, 1980; Terman & Allen, 1970). Controlled-release fertilizer sources have proven beneficial with many horticultural crops (reviewed by Maynard & Lorenz, 1979). Sulfur-coated urea and isobutylidene diurea have

increased mature orange tree yields over ammonium nitrate in Florida (Koo, 1986).

Young Citrus Tree Care

Objectives of a young citrus tree care program center on obtaining the greatest amount of growth in the shortest amount of time. There is little concern for marketable yield or fruit quality as with mature trees.

Irrigation

Information on irrigation of young citrus is limited. In Arizona, basin and trickle irrigation systems provided greater growth and lower water use of young orange trees through 5 years in the field, compared to border-flood and sprinkler systems (Rodney et al., 1977; Roth et al. 1974). The trickle system was operated daily, basin and sprinkler were operated weekly, and flood irrigations were at intervals of at least 2 weeks. Trees in the trickle treatment received 11%, in the basin treatment, 13%, and in the sprinkler treatment, 38% as much water as those in the flood treatment. Leyden (1975a) compared strip watering, ring watering, and drip irrigation on newly-planted grapefruit trees in Texas. Tree growth was similar over a 2-year period, with drip requiring about 18% and ring watering 25% of the water utilized with strip watering. Strip and ring watering were scheduled at 30% soil water depletion, and drip irrigation was scheduled on the basis of pan evaporation. De Barreda et al. (1984) used drip and basin irrigation in Spain to compare the application of varying amounts of water at the same frequency. Applications were based on coefficients of pan evaporation, and results suggested that

coefficients of 0.10-0.15, 0.20, and 0.30 for the first 3 years maintained adequate growth. They made no comparison of basin and drip irrigation methods. Split-root containers have been utilized to simulate the effects of partial root wetting of young citrus trees in Florida (Brakke et al., 1986). Preliminary results of gas exchange measurements suggested that growth may be only slightly reduced by irrigating 50-75% of the root volume compared to 100%.

Field lysimeters equipped with rain shelters have been used to study irrigation requirements of young orange trees in Florida (Aribi, 1985; Smajstrla et al., 1985). Irrigations were scheduled at matric potentials of -10, -20, and -40 kPa, which corresponded to available soil water depletions of 30, 45, and 55%. Water was applied to return the upper 60 cm of soil to field capacity, thus 23, 34, and 42 liters were applied per irrigation per tree in the -10, -20, and -40 kPa treatments, respectively. Maintaining weed-free conditions around trees resulted in a 50% reduction in water use compared to trees with a bahiagrass cover. Tree growth was greatest when irrigations were scheduled at -20 kPa and the ground was maintained weed-free.

General recommendations have been given for irrigation of newly-planted citrus in Florida. Jackson and Ferguson (1984) recommend that newly-planted trees irrigated by the basin method should be watered 2 to 3 times per week for 8 weeks, and once per week thereafter. Ziegler and Wolfe (1975) suggest applying 30-38 liters per tree each 2 weeks in the spring, with no irrigation needed in the fall. Jackson and Lawrence (1984) recommend a "generous supply" of water applied every 7-10 days.

Fertilization

Optimum nutrient levels for maximum canopy growth should be maintained by fertilization of young citrus trees (Koo & Reese, 1971). Young tree fertilization practices in Florida have changed over the years. Collison (1919) made a 10-year comparison of fertilizer rates. The standard treatment used 0.136 kg N/tree/year in year-1, and was gradually increased to 0.408 kg N/tree/year by year-10. Some plots received one-half, twice, and four times this amount. After several years, trees in the standard and one-half standard plots had larger trunk diameters than two-fold and four-fold treatments. Although not properly replicated, these data suggest as little as 0.068 kg N/year are needed for fertilization of young citrus trees. Bryan (1940) recommended applying 0.07 kg N/year per meter of canopy spread for young citrus trees in Florida.

Several field experiments conducted in the 1950s suggested that annual rates of 0.073 kg N/tree for the first 2 years were sufficient to obtain optimum tree growth on the Ridge (Rasmussen & Smith, 1961, 1962). These rates and the authors' recommended application frequency of three times during the first year and two times thereafter differed from the average grower practice. Up to seven applications per year and rates of 0.13 and 0.25 kg N/tree for the first 2 years, respectively, were not uncommon at the time.

Calvert (1969) reported that trees responded with greater growth to rates of 0.22 to 0.32 kg N/tree than 0.11 kg/tree when growing in the flatwoods in marginal soils. Furthermore, four applications per year were superior to three. These data illustrate

the importance of considering soil type when evaluating fertilization needs.

There is a wide range of adequate fertilization methods available for growers, and considerable judgement is required to choose the most efficient. Current recommendations (Koo et al., 1984) call for 0.18-0.22 kg N/tree in year-1 and 0.29-0.36 kg N/tree in year-2. Other elements should be applied in proportion with N in the following ratio: N-1, P_2O_5-1, K_2O-1, Mg-1/5, Mn-1/20, Cu-1/40, B-1/300.

Controlled-release N sources have been used for fertilization of young citrus trees. Controlled-release isobutylidene diurea increased growth of young container-grown citrus compared to soluble N sources (Khalaf, 1980; Khalaf & Koo, 1983). In the same study, isobutylidene diurea and sulfur coated urea reduced N leaching losses compared to soluble sources. Fucik (1974) similarly demonstrated an increase in growth of young, container-grown citrus trees with controlled-release compared to soluble fertilizer. Jackson & Davies (1984) reported similar growth rates of young, field-grown 'Orlando' tangelo trees occurred with sulfur coated urea and a soluble fertilizer source, but application frequency was reduced by 50% with sulfur coated urea.

<u>Container- and Field-grown Nursery Trees</u>

Cultural practices and growing conditions of any nursery affect growth and development of plant material in the nursery, but also after transplanting to the field. Production systems for field and greenhouse citrus nurseries are well-developed, however, little effort has gone into understanding the effect of nursery tree

characteristics on growth after field planting. Webber (1932), with 'Washington' navel orange, and Gardner and Horanic (1959) with 'Parson Brown' and 'Valencia' orange reported no relationship between initial size of nursery trees and mature tree size. Effects on precosity were not reported. Grimm (1956, 1957) stated the most important factor affecting initial growth of bare-rooted nursery trees was the protection of roots while they were out of the ground.

The advantages of containerized, greenhouse nursery systems are varied and include greater control over the production system, lower land requirement, and shorter production cycle (Castle et al., 1979; Moore, 1966; Platt & Opitz, 1973; Richards et al., 1967). Nursery trees produced under these conditions are much different from the traditional field-grown nursery trees. Shoot:root ratio of nursery trees is substantially increased in this system over the field system (W.S. Castle, Citrus Research and Education Center, Lake Alfred, personal communication). Very high nitrogen and water applications, reduced light intensity, and root restriction by containers may all contribute to this, as all of these factors have been shown to increase shoot:root ratio. Vigorous root growth is altered when the available soil volume is permeated, at which time the growth pattern may be shifted to fibrous roots (Castle, 1978). This results in a substantial increase in the proportion of fibrous to non-fibrous roots of container-grown compared to field-grown citrus nursery trees (W.S. Castle, Citrus Research and Education Center, Lake Alfred, personal communication).

Initial expansion of the root system is critical for successful establishment of any containerized transplant (Castle, 1987). The

potential for rapid initial root growth of containerized forest seedlings has been studied in detail and is directly linked to survival and tree growth after field planting. Container characteristics such as size and shape have altered post-planting shoot and root growth of container-grown transplants (Elam et al., 1981; Hiatt & Tinus, 1974; Hite, 1974; Tinus & Owston, 1984; Van Eerden & Arnott, 1974). Container medium has also affected tree growth following field planting in a number of species (Elam et al., 1981; Hellum, 1981) including citrus (Warneke et al., 1975). Elam et al. (1981) reported considerable variation between oak species with respect to the effects of container and media characteristics on growth. Less root growth of pine seedlings occurred as the length of time plants were maintained in containers was lengthened (Hellum, 1981). Reduced irrigation frequency or nitrogen fertilization prior to removal from the nursery has been used to increase root and shoot growth of container-grown trees (Rook, 1973; Timmis, 1974; Tinus & Owston, 1984).

Drying of container medium after planting in the field may induce plant water stress in some cases. A substantial increase in drainage out of the medium occurred following removal from a container and placement in contact with field soil (Costello & Paul, 1975; Nelms & Spomer, 1983; Warneke et al., 1975). Low survival rates have been attributed to severe water stress due to these conditions.

Post-plant growth comparison of container- and field-grown citrus nursery trees has been conducted in Texas. Leyden and Timmer (1978) observed growth of grapefruit on sour orange trees for 2.5

years in the field and concluded that container-grown trees would be less productive and smaller than field-grown trees during the early years of bearing. Maxwell and Rouse (1980, 1984) reported that container-grown grapefruit on sour orange trees remained smaller than field-grown trees through 10 years after planting, but yield did not differ. Container-grown trees were not produced under greenhouse conditions as is the case in Florida, and field-grown trees were transplanted as ball and burlapped stock in both studies.

CHAPTER III

MICROSPRINKLER IRRIGATION AND GROWTH OF YOUNG 'HAMLIN' ORANGE TREES. I. CANOPY GROWTH AND DEVELOPMENT

Introduction

Comparable or increased growth or yield and decreased water use by mature citrus has been observed in several countries when micro irrigation systems were compared with flood or high volume sprinkler systems (Alijbury et al., 1974; Bester et al., 1974; Bielorai, 1982; Bielorai et al., 1981; Legaz et al., 1981; Roth et al., 1981). Some have found that increasing the area of coverage by irrigation systems has increased growth and yield of mature citrus (Moreshet et al., 1983; Koo, 1978, 1985; Zekri, 1984). Smajstrla and Koo (1984, 1985) reported an increase in yield over non-irrigated trees in Florida when irrigating between 5 and 50% of the under-tree canopy area of mature citrus. Koo and Tucker (1974) recommended that 60% of a citrus tree's root volume be covered by an irrigation system.

A number of studies have been conducted comparing growth and development of young citrus trees using various irrigation methods. Border-flood, sprinkler, basin, and trickle irrigation methods were compared on young 'Campbell Valencia' orange trees in Arizona (Rodney et al. 1977; Roth et al. 1974). Tree growth and yield were greater and water use lower in the first 5 years with the basin and

trickle systems compared with the other systems. Growth of young navel orange trees has been evaluated using drip and basin irrigation methods in Spain (De Barreda et al., 1984). Treatments consisted of applying different volumes of water at the same frequency based on coefficients of pan evaporation. Coefficients were increased with each year of age, suggesting that coefficients of 0.10-0.15, 0.20, and 0.30 for the first 3 years maintained adequate growth. Leyden (1975a) compared irrigation systems on newly-planted 'Star Ruby' grapefruit trees in Texas. Strip and ring watering were scheduled based on 30% soil water depletion, and drip irrigation was scheduled on the basis of pan evaporation. Drip irrigation used 18 and ring watering used 25% of the cumulative irrigation water required for strip watering. Tree growth was similar between the three systems over a 2-year period.

Irrigation of young citrus trees in Florida is also necessary to obtain optimum growth. Irrigation studies on newly-planted 'Valencia' orange trees were conducted using a series of lysimeters under rain shelters (Aribi, 1985; Smajstrla et al., 1985). Comparing irrigation scheduling at matric potentials of -10, -20, and -40 kPa, tree growth was greatest when irrigations were scheduled at -20 kPa and the ground was maintained weed-free. Split-root containers were utilized to simulate the effects of partial root-volume wetting of young 'Hamlin' orange trees (Brakke et al., 1986). Preliminary results of gas exchange measurements suggested that growth may be only slightly reduced by irrigating 50-75% of the root volume compared to 100%. Allen et al. (1985)

stated that frequent irrigation of containerized citrus rootstock seedlings was required to sustain high photosynthesis.

An estimated 6-10 million young citrus trees are being planted in Florida annually (Jackson et al., 1986), however, water requirements, irrigation scheduling, and growth responses to microsprinkler irrigation have not been studied under field conditions. The purpose of this field study using 'Hamlin' orange trees was to determine 1) the optimum level of soil water depletion at which irrigations should be scheduled to maximize growth, 2) the amount of irrigation time needed to replenish soil water to field capacity, and 3) the effect of irrigation pattern on growth of second season trees.

Materials and Methods

Site and Soil Characteristics

Three field experiments were conducted at the Horticultural Research Unit near Gainesville, FL, in 1985, 1986, and 1987. Soil type was Kanapaha sand (Carlisle et al., 1988) (loamy, siliceous, hyperthermic, Grossarenic, Paleaquults) underlain by a hardpan. Particle size distribution was 93.4% sand, 3.9% silt, and 2.7% clay. The soil has a field capacity of ca. 11.3%; permanent wilting point, ca. 2%; mean bulk density, 1.56 g/cm^3; pH, 6.4; and percent organic matter, 0.65. A desorption soil water characteristic curve was determined using a vacuum desiccator employing undisturbed soil cores in weighable pressure cells fitted with fritted glass plates (Fig. 3-1). Saturated hydraulic conductivity was 9.3 cm/hr as determined by using undisturbed cores in a constant head permeameter.

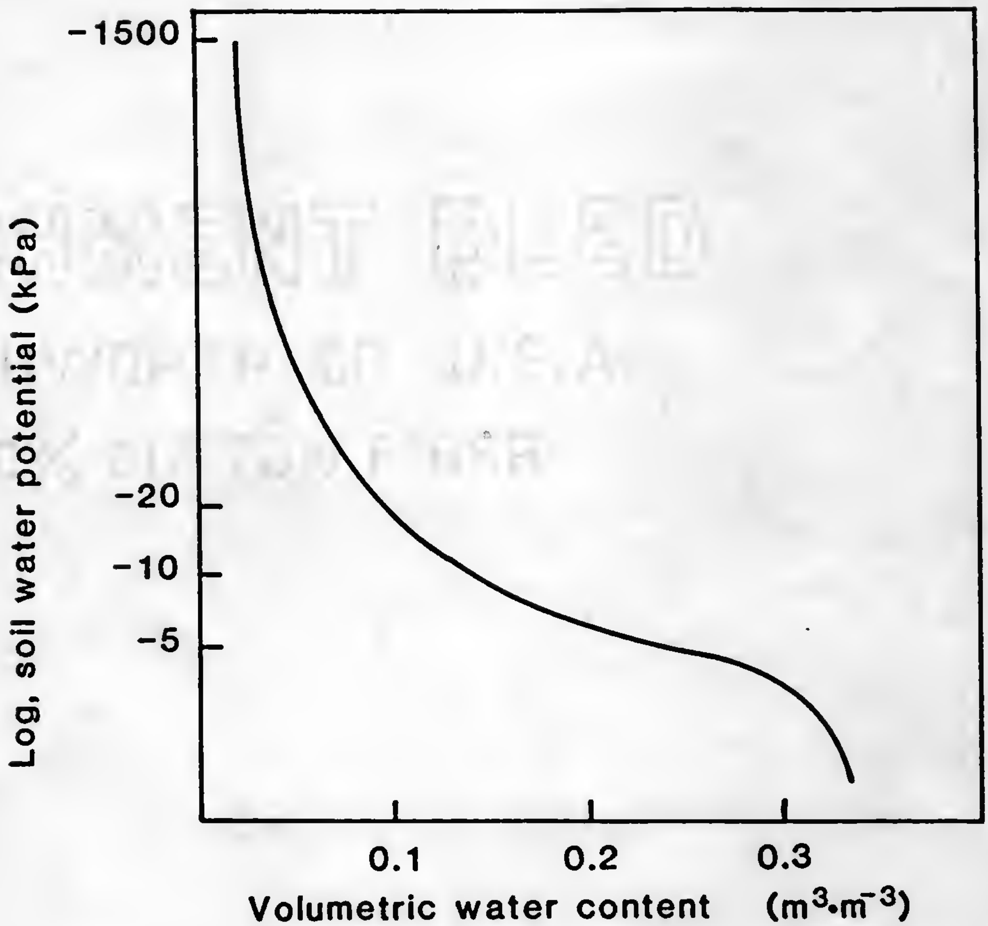

Fig. 3-1. The relationship between soil water content and water potential of Kanapaha sand at the Horticultural Unit.

Beds (16.75 m width x 0.60-0.75 m height x 85 m length) were constructed in March, 1985 to facilitate drainage and simulate flatwoods growing conditions. Ground water table was monitored through observation wells located in the tree rows and averaged 1.1 m deep between June and Sept. (rainy season) with a minimum of 0.45 m, and greater than 1.6 m during other months. A ground cover of bahiagrass was developed between rows and was mowed as needed, while tree rows (about 2.1 m width) were maintained weed-free with herbicides.

Irrigation Treatments

The irrigation system was designed so that each treatment could be monitored and controlled individually using a flow meter and pressure gauge controlled by a gate valve. Water was conveyed from a manifold through 2.54 cm PVC main lines and 1.91 cm black polyethylene laterals down tree rows. Three tubes, one per treatment, were positioned 50-55 cm west of each tree row which ran the full length of the bed, allowing unrestricted randomization at each experimental site. Irrigation water containing 287 mg/liter total dissolved solids was applied via 90°, 38 liter/hr Maxijet™ microsprinkler emitters positioned 1 m northwest of each tree. This positioning also provides optimum cold protection for young citrus trees (Rieger et al., 1986). The area of ground covered was about 5 m^2 for these emitters. Irrigation was controlled by hand regulation of gate valves to maintain the system pressure at about 140 kPa.

Irrigation scheduling was based on soil water content as monitored by the neutron scattering method (Hillel, 1982) using a Troxler Model 1255 neutron probe. A calibration curve for the

neutron probe was developed by the gravimetric method (Fig. 3-2) (Hillel, 1982). Access tubes constructed of 48 mm i.d. aluminum irrigation tubing were driven into the soil 1 m from the emitters and 35 cm from each of four randomly chosen trees per treatment in 1985 and 1986 and from each of three trees per treatment in 1987. Soil moisture measurements were made daily or as needed during the rainy season at a depth of 30 cm. The soil volume around the tree was irrigated to field capacity when a prespecified level of available soil water depletion (SWD) was reached. Irrigations were initiated when any of the four neutron probe readings reached the level of SWD in 1985 and 1986, and based on the average of the three neutron probe readings in 1987. Three levels of irrigation were designated as high (20% SWD), moderate (45% SWD), and low (65% SWD).

The amount of irrigation water needed for each treatment to replenish soil moisture to field capacity was determined during the first few irrigations in 1985. Soil water content at 30 cm depth was monitored using the neutron scattering method at 15-min intervals following an irrigation. By initially varying the length of irrigation time, the approximate length of time needed for each treatment to return soil moisture from the specified SWD level to field capacity was determined.

Plant Material and Experimental Design

Commercially obtained, bare-rooted 'Hamlin' orange [*Citrus sinensis* (L.) Osb.] on sour orange (*C. aurantium* L.) trees were planted on double row beds at 7.6 m between and 4 m within rows. Initial trunk diameter averaged 1.2, 1.4, and 1.5 cm in 1985, 1986, and 1987, respectively. A randomized complete block design

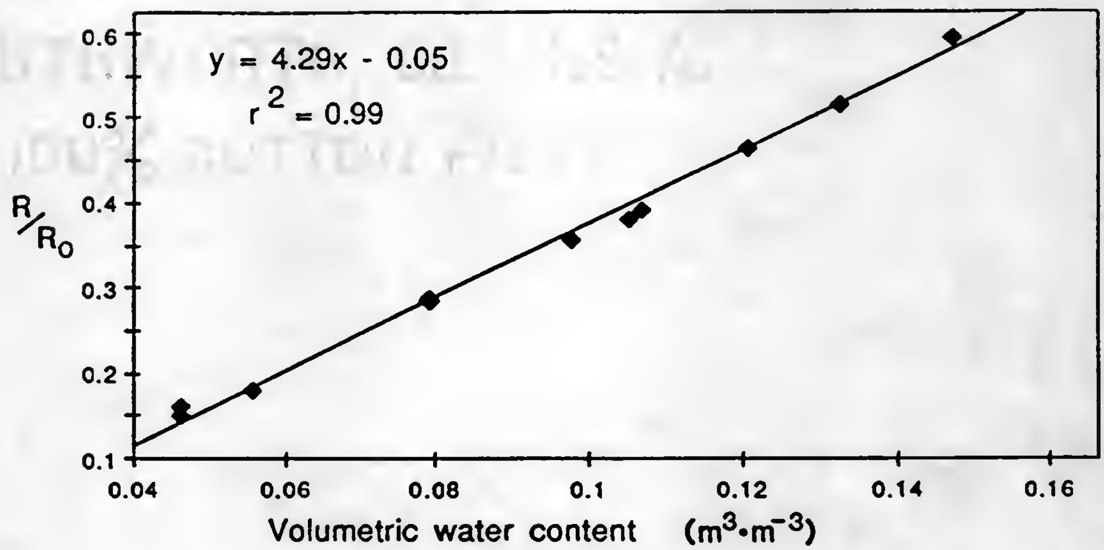

Fig. 3-2. The relationship between neutron probe ratio and volumetric water content in Kanapaha sand at the Horticultural Unit. R = counts per min. in soil, R_o = standard counts per min.

consisting of four blocks was utilized in 1985 and 1986, employing six single-tree replications per treatment per block, resulting in a total of 24 replications per treatment. A completely randomized design with 13 replications was utilized in 1987 because the block effect was not significant in 1985 and 1986. Trees were planted on 10-12 May, 3-4 May, and 2 April for the 1985, 1986, and 1987 experimental periods, respectively. All trees were irrigated every 2 days during an establishment period of 10-14 days in each experiment. Commercial fertilization rates recommended for Florida (Koo et al., 1984) were followed using an 8N - 2.6P - 6.6K - 2Mg - 0.2Mn - 0.12Cu - 0.2Zn - 1.78Fe dry formulation. Four applications were made at regular intervals in 1985, while five were made in 1986 and 1987.

Plant Measurements

Seasonal measurements. Shoot growth was measured throughout the growing season during 1985 and 1986. As shoots began growth, three per tree were randomly chosen and tagged. Shoot length was measured with a ruler at about 7-day intervals thereafter. The length and width of the third leaf from the shoot base was measured at the same time. This leaf position was used because the bottom two leaves were many times of unrepresentative size or shape. Leaf expansion was determined by using the product (x) of length and width in an equation for leaf area (area = $2.33 + 0.63x$, $r^2 = 0.94$). This equation was derived from a sample of 100 leaves of various sizes by linear regression of leaf area, determined with a LI-COR Model LI-3000 leaf area meter, on leaf length x width (data not shown). Final shoot length and leaf area were compared, as were

expansion rates. Rates were calculated on a daily basis by subtracting the initial length or area when shoots were tagged from the final length or area, and dividing by the number of days required to reach the final size. Although shoot and leaf expansion were not measured in 1987, dates of initial shoot growth were recorded for each tree in each of the three flushes. Intervals of about 7 days were again used. The percentage of the tree population growing for each irrigation treatment and at each date was calculated for all 3 years.

Canopy and trunk measurements. Canopy height and width in two directions were measured initially and in December of each year (15 May and 10 Dec. 1985, 6 May and 7 Dec. 1986, 4 April and 18 Dec. 1987). Width measurements were averaged and canopy volume was calculated as $(4/3)(3.14)(1/2H)(1/2W)^2$, where H=height and W=width (Westwood, 1978). This formula most closely approximates the canopy shape of a young tree which is taller than it is wide. A mark was painted with latex paint about 5 cm above the bud union where trunk diameter was measured in two directions with a hand-held caliper. Measurements were made on the same days as canopy measurements. The two measurements were averaged and trunk cross sectional area calculated. In addition total shoot length for each tree was measured with a ruler within 1 week of planting dates.

Final measurements. Root excavation of 20, 21, and five plants per treatment in 1985, 1986, and 1987, respectively, was conducted by hand in Dec. of each year. Initially a circular trench was dug about 40 cm deep at a distance of 120 cm from the trunks. The few roots extending beyond this distance were individually recovered by

excavation. The entire shallow root system was recovered almost completely intact by undercutting it to a depth of 40 cm until the sand loosened exposing the roots. The depth was increased near the trunk to ensure recovery of the taproots. This operation was not difficult due to the loose, sandy nature of the soil and shallowness of the root systems. Trees were taken indoors where roots and canopies were separated. Root growth and distribution are discussed in Chapter IV.

Leaves were removed from canopies for fresh weight determination. Leaf area was calculated from the fresh weight utilizing a linear relationship obtained from sampling eight trees. Leaf area was measured on these trees using a LI-COR Model LI-3000 leaf area meter. The relationship shown in Fig. 3-3 was derived from linear regression of leaf area on fresh weight. Total shoot length was measured with a ruler following leaf removal.

A random sample of four, six, and five trees in 1985, 1986, and 1987, respectively, were separated into the three growth flushes that had occurred during the experimental period. Shoots within each flush were counted and measured with a ruler. Mean and total shoot length and mean shoot number were calculated for each growth flush.

All canopy parts were dried in an oven at 80° C to determine canopy dry weight.

<u>Analysis of Data</u>

Shoot length, leaf area, and expansion rates measured throughout the growing season were analyzed separately for each of the three flushes in 1985 and 1986. Shoots in each flush were

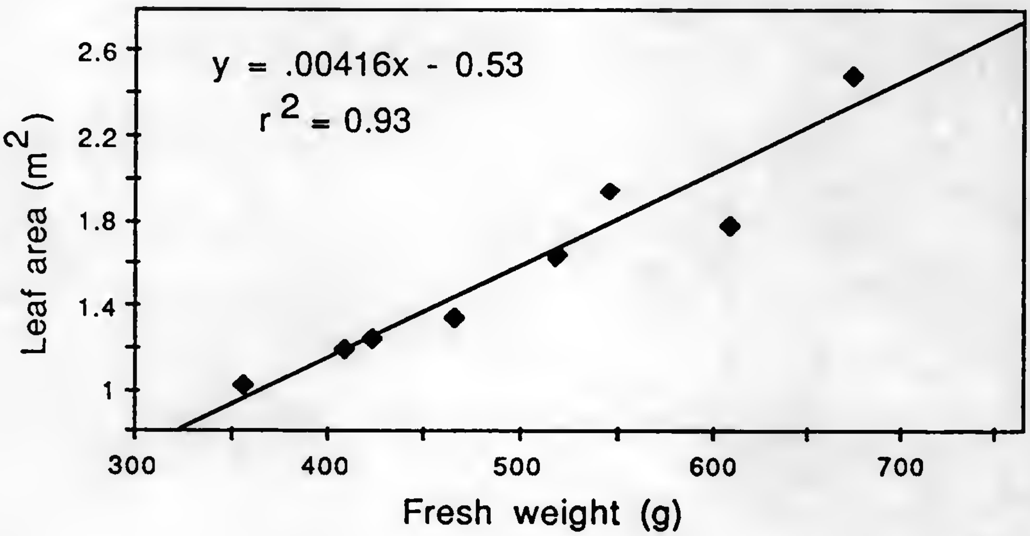

Fig. 3-3. Relationship of leaf area and fresh weight from eight representative 'Hamlin' orange trees after 8 months in the field.

blocked into groups of shoots that had begun growth within periods of time not exceeding 2 weeks in length. Data were analyzed by analysis of variance as a treatment x time period factorial experiment.

Data concerning the percentage of each treatment population growing throughout the season were analyzed using linear, quadratic, and cubic regression models. Models with the highest level of significance and best fit for each treatment population were chosen. Resulting equations were tested by analysis of covariance for homogeneity within each growth flush.

Shoot number, mean length, and total length measured by dividing excavated trees into different flushes were analyzed by a split-plot analysis with treatments as main plots and flushes as subplots.

Final plant measurements from different years were analyzed separately. Data on dry weight and leaf area were subjected to analysis of variance and data on canopy volume, trunk cross sectional area, and shoot length to analysis of covariance to standardize differences in initial plant measurements. Where irrigation levels were significantly different, Williams' (Williams, 1971) test was used to compare means. This test is useful in cases where curve-fitting is not desired or is difficult due to a small number of dose levels. It was employed due to the small number of treatments to compare irrigation levels to the most frequent scheduling treatment to determine the level at which a significant response occurred.

Microsprinkler Irrigation Spray Patterns

Two experiments were conducted on the same site to test the effect of microsprinkler irrigation spray pattern on 'Hamlin' orange tree growth the second season in the field. Site characteristics were as described for microsprinkler irrigation scheduling experiments, except trees were set 3.4 m apart in the rows. Two microsprinkler spray patterns were utilized, 90° and 180°. Approximately 89 liters were applied per tree at each irrigation, delivered through 89 liter/hr emitters and distributed over ca. 5.9 and 9.3 m^2 of ground area for the 90° and 180° patterns, respectively.

Treatments begun on 10 May 1986 in the first experiment on trees planted in May 1985. The factorial experiment performed from May 1985 - May 1986 was used to study two types of nursery trees receiving four types of fertilizer (Chapters VI & VII). Each 2 x 4 treatment combination had been assigned to two trees within each of four randomized complete blocks in 1985. Subsequently, each spray pattern was randomly assigned to one of the two trees of each tree type - fertilizer type combination in May 1986. Treatments were begun on 2 May 1987 in the second experiment on trees planted in May 1986 (Chapters VI & VII). Each 2 x 4 treatment combination had been assigned to two trees within each of two randomized complete blocks in 1986. Each spray pattern was again randomly assigned to one of the two trees of each tree type - fertilizer type combination in May 1987.

Trees were grown during the first year under 90° microsprinkler irrigation on 20% SWD scheduling. During the two experimental

periods irrigations were scheduled when 20% SWD was reached in accompanying irrigation scheduling experiments.

Trunk cross sectional area and canopy volume were measured as described previously. Measurements were made on 9 May and 7 Dec. 1986 for the first experiment and 30 April and 18 Dec. 1987 for the second. Measurements were analyzed separately for the two experimental periods. Split-plot analysis was utilized with fertilizer type x tree type as main plots and irrigation patterns as subplots. Analysis of covariance was used to standardize differences in plant measurements from the beginning of the experimental periods.

Environmental Variables

Rainfall was recorded daily with a Science Associates Model 503 rain gauge located about 200 m east of the experimental site. Relative humidity and temperature were recorded continuously using a hygrothermograph (WEATHERtronics Model 5021) located at the experimental site.

Results and Discussion

Irrigation Amount and Frequency

Thirty-eight, 50, and 76 liters/tree were needed for the high, moderate, and low irrigation treatments, respectively, to return the soil to field capacity (Table 3-1). These durations resulted from measurements of soil moisture content by the neutron probe at a depth of 30 cm, and did not take into account the level of depletion in the surface soil. Irrigation durations of 1-2 hr were used with the 38 liter/hr, 90° emitters used in this study. An industry survey has shown that many times growers do not take advantage of

Table 3-1. Duration of irrigation and amount of water applied at each irrigation as related to soil water depletion for young 'Hamlin' orange trees.

Soil water depletion (%)[z]	Irrigation duration (hr)	Amount applied	
		liters/ tree	mm[y]
20 (High[x])	1.0	38	7.5
45 (Mod.)	1.3	50	10.0
65 (Low)	2.0	76	15.1

[z]Based on neutron probe measurements at 30 cm depth.
[y]Based on area wetted by emitters of about 5 m^2.
[x]High, moderate, and low refers to irrigation frequency.

the water savings that are possible with micro irrigation systems due to excessive operating time (Hutcheson & Bellizio, 1974).

The number of irrigations needed to maintain soil moisture at the specified levels differed greatly (Table 3-2). An average of 31, 11, and 2 irrigations per season were required for the high, moderate, and low schedules, respectively. During dry periods, irrigations were 2-3 days apart in the high treatment and 4-6 days apart in the moderate schedule. The number of irrigations in the moderate schedule varied from year-to-year more than the other scheduling treatments. The 16 irrigations needed in 1986 were nearly twice the number needed in the other years. Different factors were probably responsible for the reduced number of irrigations needed in 1985 and 1987 compared with 1986. In 1985, more frequent rainfall (Fig. 3-4) did not allow SWD to reach 45% (moderate) as often as occurred in 1986 (Fig. 3-5). Rainfall was not responsible for the reduced number of irrigations in 1987 since frequency and cumulative amount of rainfall was lower (Fig. 3-6) than in 1986. Tree growth and water use was less during the 1987 season regardless of irrigation treatment, thus the plants required fewer irrigations. Over the 3-year period, trees in the moderate and low treatments received respectively 49 and 13% as much irrigation water as those in the high treatment (Table 3-2).

Individual Shoot and Leaf Growth - Seasonal Measurements

During the first flush of 1985 trees under the high and moderate treatments made significantly greater average shoot growth ($P<.0165$) and leaf growth ($P<.0315$) than trees under the low treatment (Table 3-3). Shoot and leaf size in the second and third

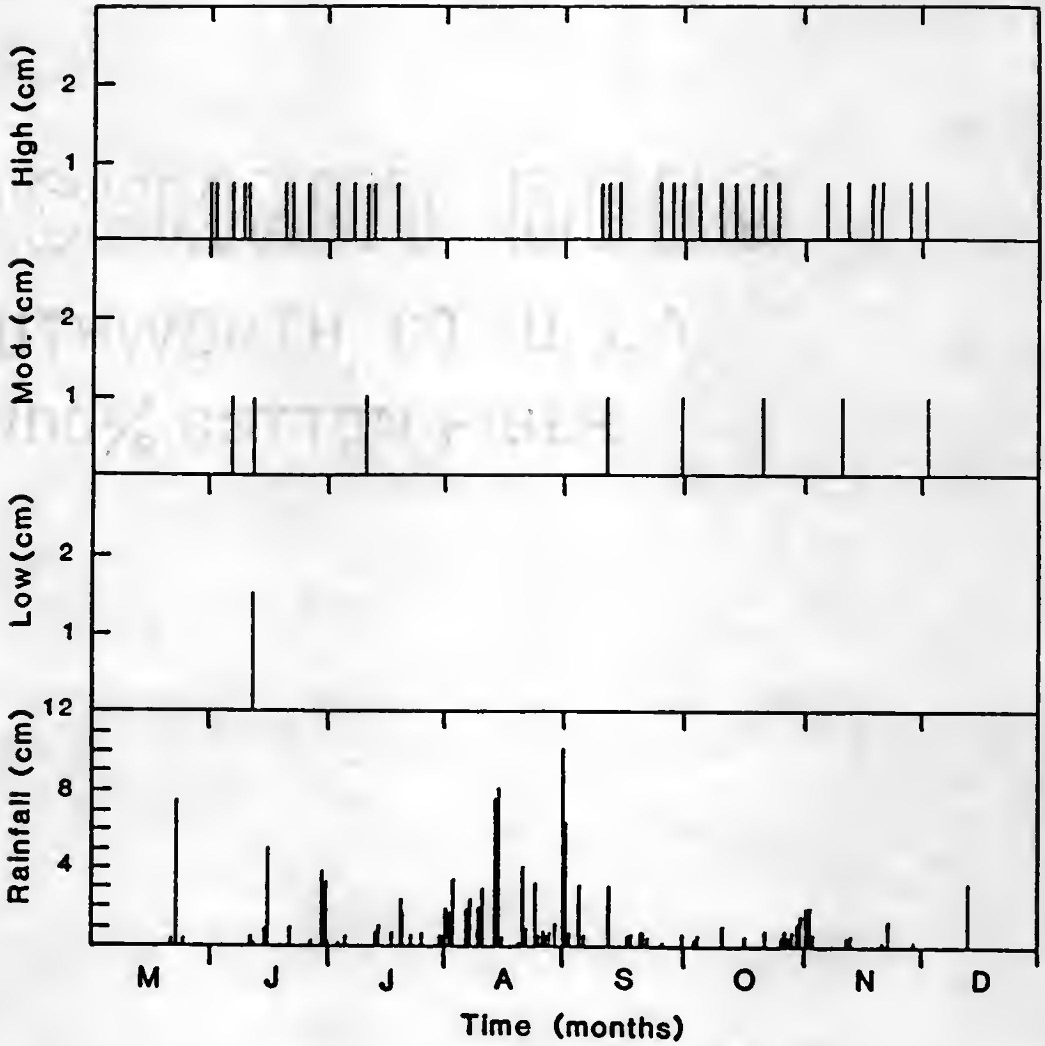

Fig. 3-4. Distribution of rainfall and microsprinkler irrigation at the Horticultural Unit, May-Dec. 1985. High, moderate, and low refer to irrigation treatments based on 20, 45, and 65% soil water depletion, respectively.

Table 3-2. Number of irrigations and cumulative water applied for young 'Hamlin' orange trees under scheduling treatments based on soil water depletion.

Soil water depletion (%)[z]	Irrigations/ year (no.)	Cumulative water applied		Cumulative irrigation and rain (cm)
		liters/ tree	(cm)[y]	
		1985		
20 (High[x])	31	1173.5	23.3	141.2
45 (Mod.)	8	402.8	8.0	125.9
65 (Low)	1	75.7	1.5	119.4
		1986		
20 (High)	35	1324.9	26.4	145.8
45 (Mod.)	16	805.5	16.0	135.5
65 (Low)	4	302.8	6.0	125.5
		1987		
20 (High)	27	1022.0	20.3	112.1
45 (Mod.)	10	503.5	10.0	101.8
65 (Low)	1	75.7	1.5	93.3

[z]Based on neutron probe measurements at 30 cm depth.
[y]Based on area wetted by emitters of about 5 m^2.
[x]High, moderate, and low refers to irrigation frequency.

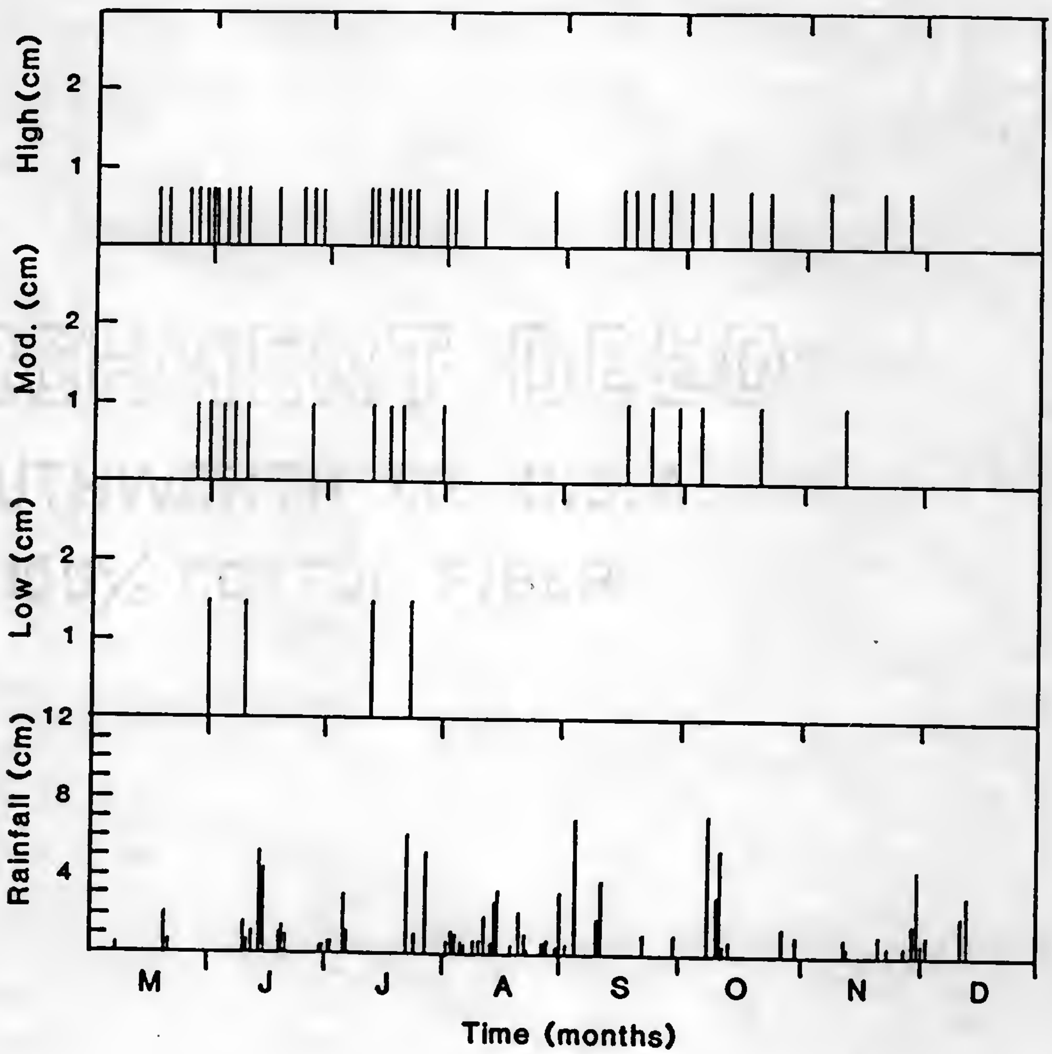

Fig. 3-5. Distribution of rainfall and microsprinkler irrigation at the Horticultural Unit, May-Dec. 1986. High, moderate, and low refer to irrigation treatments based on 20, 45, and 65% soil water depletion, respectively.

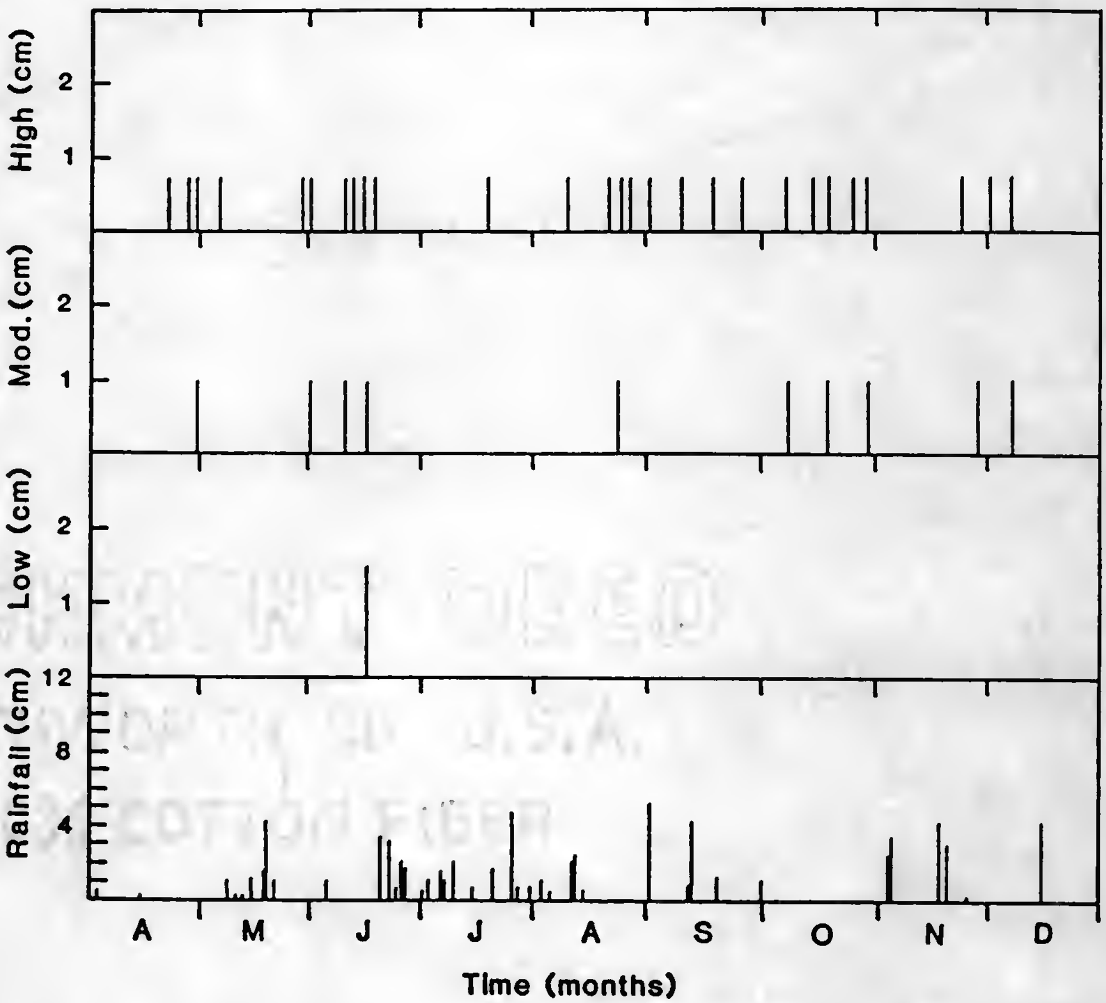

Fig. 3-6. Distribution of rainfall and microsprinkler irrigation at the Horticultural Unit, April-Dec. 1987. High, moderate, and low refer to irrigation treatments based on 20, 45, and 65% soil water depletion, respectively.

Table 3-3. Shoot and leaf sizes and expansion rates for three growth flushes of young 'Hamlin' orange trees as influenced by irrigation based on soil water depletion, 1985.

Soil water depletion (%)	Shoot			Leaf		
	n	length (cm)	rate (cm/day)	n	area (cm^2)	rate (cm^2/day)
			Flush one (5/30 - 6/25)[z]			
20 (High)	70	9.7	0.5	67	22.6	0.8
45 (Mod.)	69	10.8	0.6	67	23.3	0.9
65 (Low)	64	8.6	0.4	61	19.6	0.7
SE[y]		0.7	0.1		1.4	0.1
			Flush two (7/12 - 8/19)			
20 (High)	49	21.5	1.2	49	38.7	1.4
45 (Mod.)	40	22.3	1.3	40	40.9	1.6
65 (Low)	34	17.4	1.0	33	28.1	1.0
SE		ns	ns		ns	ns
			Flush three (9/11 - 11/25)			
20 (High)	36	28.8	1.1	37	44.1	1.7
45 (Mod.)	28	31.5	1.2	28	43.8	1.6
65 (Low)	10	25.8	1.2	10	40.7	1.5
SE		ns	ns		ns	ns

[z]Range in dates of growth initiation.

[y]SE = standard error of mean.

flush were not dependent on irrigation treatments, although the low treatment consistently had the lowest means.

Irrigation treatment effects on growth of the first flush in 1986 were in contrast to 1985, in that trees in the moderate and low treatments had greater individual shoot length ($P<.0077$) and leaf area ($P<.0005$) than trees in the high treatment (Table 3-4). A different pattern occurred in flush two, when shoot length of trees in the high and moderate treatments was larger ($P<.0117$) than those in the low treatment. Leaf size in flush two and both shoot and leaf size in flush three were independent of irrigation treatments. Shoot length, leaf area, and rates of growth generally increased from flush one to flush three in both 1985 and 1986.

Shoot and leaf expansion rates averaged less in flush one than the other flushes. Similarly, growth rates of the spring flush of mature orange trees in Florida, estimated as gain in biomass, were less than the summer flush (Syvertsen et al., 1981). Shoot growth rates ranged from 0.4-1.0 cm/day in flush one and 0.7-1.4 cm/day in the other flushes, which was considerably more than previously reported for mature trees of various citrus species in subtropical India (Krishnamurthi et al., 1960).

Shoot Number and Length Within Flushes - Final Measurements

Shoot number, average shoot length, and total shoot length were not significantly affected by irrigation treatments in 1985. Cumulative shoot length during the season (three flushes summed) was 650, 760, and 537 cm/tree in the high, moderate, and low treatments, respectively. Lack of significant differences may have been be due to the small number of replications (four) or to the loss in

Table 3-4. Shoot and leaf sizes and expansion rates for three growth flushes of young 'Hamlin' orange trees as influenced by irrigation based on soil water depletion, 1986.

Soil water depletion (%)	Shoot n	Shoot length (cm)	Shoot rate (cm/day)	Leaf n	Leaf area (cm^2)	Leaf rate (cm^2/day)
		Flush one (5/25 - 6/17)[z]				
20 (High)	65	13.7	0.8	65	15.9	0.6
45 (Mod.)	45	17.5	1.0	44	22.0	0.9
65 (Low)	49	17.8	1.0	49	21.4	0.7
SE[y]		1.5	0.1		1.9	0.1
		Flush two (7/7 - 9/13)				
20 (High)	61	20.3	1.1	60	31.3	1.1
45 (Mod.)	39	21.6	1.1	44	34.9	1.3
65 (Low)	40	17.4	0.7	40	30.4	1.1
SE		1.5	0.1		ns	ns
		Flush three (8/30 - 12/3)				
20 (High)	58	30.6	1.4	53	46.6	2.1
45 (Mod.)	49	31.7	1.4	46	46.3	1.8
65 (Low)	45	28.2	1.3	42	37.3	1.5
SE		ns	ns		ns	ns

[z]Range in dates of growth initiation.

[y]SE = standard error of mean.

precision in the whole plot analysis of treatments in the split-plot design. Across all treatments, however, individual shoot length significantly increased (P<.0001) and shoot number per flush decreased (P<.0108) successively from flush one to flush three (Table 3-5). Flushes two and three added significantly (P<.0124) more total shoot length than flush one during the season (Table 3-5).

In contrast, irrigation treatments significantly affected shoot number per flush (P<.0079) and total shoot length per flush (P<.0164) in 1986, although there was no effect on mean shoot length (Table 3-6). A mean of 19 shoots per flush occurred on trees in the high treatment, with 13 and 9 shoots per flush occurring on trees in moderate and low treatments, respectively (SE=3). Total length per flush was 335 cm for trees in the 20% SWD treatment, and 258 and 134 cm for trees in the 45 and 65% SWD treatments (SE=64). Reduction in total length per flush by 65% SWD was more pronounced in flush three (Table 3-6). Cumulative shoot length for the entire season was 1004 cm in high, and 774 and 402 cm in moderate and low treatments, respectively. As in 1985, mean shoot length, pooled over the treatments, significantly (P<.0001) increased from flush one to flush three, while flush three had significantly (P<.0012) fewer shoots than flushes one and two (Table 3-6). These trends balanced total length of individual flushes such that the flushes were not different.

Irrigation treatments did not affect mean shoot length or number in 1987, but significantly (P<.0204) altered total shoot length per flush, producing a total length of 408, 235, and 212 cm

Table 3-5. Shoot number, average shoot length, and total shoot length for three growth flushes of young 'Hamlin' orange trees as related to irrigation based on soil water depletion, 1985.

Soil water depletion (%)	Shoot no.[z]	Shoot length (cm)[z]	Total length (cm)[z]
	Flush one (5/30 - 6/25)[y]		
20 (High)	17	9.5	163.0
45 (Mod.)	15	7.9	118.7
65 (Low)	18	7.9	146.4
Mean	17	8.4	142.7
	Flush two (7/12 - 8/19)		
20 (High)	13	20.5	261.3
45 (Mod.)	10	28.2	289.1
65 (Low)	8	25.7	211.7
Mean	10	24.8	256.4
	Flush three (9/11 - 11/25)		
20 (High)	7	34.8	225.9
45 (Mod.)	11	32.2	352.4
65 (Low)	4	42.9	179.1
Mean	7	36.6	262.1
SE[x]	2	3.4	36.9

[z]Means of 4 trees/treatment.
[y]Range in dates of initiation.
[x]SE for comparison of means among growth flushes. Comparison among irrigation levels within growth flushes is inappropriate since irrigation x flush interaction is not significant.

Table 3-6. Shoot number, average shoot length, and total shoot length for three growth flushes of young 'Hamlin' orange trees as related to irrigation based on soil water depletion, 1986.

Soil water depletion (%)	Shoot no.[z]	Shoot length (cm)[z]	Total length (cm)[z]
	Flush one (5/25 - 6/17)[y]		
20 (High)	22	13.1	284.3
45 (Mod.)	16	13.0	203.7
65 (Low)	12	10.8	126.3
Mean	16	12.3	201.9
	Flush two (7/7 - 9/13)		
20 (High)	23	15.9	366.4
45 (Mod.)	15	18.2	283.5
65 (Low)	12	20.1	234.1
Mean	17	18.1	301.1
	Flush three (8/30 - 12/3)		
20 (High)	12	29.5	353.6
45 (Mod.)	9	33.4	286.7
65 (Low)	2	22.9	41.7
Mean	8	29.5	219.9
SE[x]	3	1.8	ns

[z]Means of 6 trees/treatment.
[y]Range in dates of initiation.
[x]SE for comparison of means among growth flushes. Comparison among irrigation levels within growth flushes is inappropriate since irrigation x flush interaction is not significant.

of growth per flush (SE=59) in the high, moderate, and low treatments, respectively (Table 3-7). As in 1986, the treatment effect was most pronounced in flush three. Mean shoot length significantly increased ($P<.0001$) and shoot number decreased ($P<.0001$) successively from flush one to flush three, although total length was not different among the three flushes. Cumulative shoot length for the season averaged 1225 cm for the high, and 706 and 635 cm for the moderate and low treatments.

Severe defoliation shortly after transplanting trees from the nursery to the field in 1987, possibly due to greasy spot, produced a large number of short shoots during flush one. An average of 68 shoots were initiated per tree, compared to 17 and 16 in 1985 and 1986. Although these shoots in 1987 were much shorter than in the other years, total shoot length in flush one was greater due to the large number of shoots.

There was no uniform effect of irrigation treatment on average shoot length or leaf size. This seems in contrast to the well-established effect of decreased organ expansion due to water deficits (Hsiao, 1973). However, Hanson and Hitz (1982) state that under conditions of extreme diurnal variation in leaf water status, expansion may be inhibited during the day, but long-term growth may not be affected in some plants. There was little contribution of soil water deficit to the pronounced midday decreases in xylem potential during the early summer in this study, but a considerable decrease in CO_2 assimilation occurred with increased soil water deficit (Chapter V). In contrast to the lack of effect on average shoot length, treatments more consistently affected the number of

Table 3-7. Shoot number, average shoot length, and total shoot length for three growth flushes of young 'Hamlin' orange trees as related to irrigation based on soil water depletion, 1987.

Soil water depletion (%)	Shoot no.[z]	Shoot length (cm)[z]	Total length (cm)[z]
	Flush one (4/12 - 5/6)[y]		
20 (High)	77	4.9	376.4
45 (Mod.)	63	4.0	254.8
65 (Low)	64	4.2	264.5
Mean	68	4.4	297.4
	Flush two (6/18 - 8/2)		
20 (High)	22	16.2	362.4
45 (Mod.)	21	12.3	259.1
65 (Low)	20	11.0	216.8
Mean	21	13.1	277.4
	Flush three (8/9 - 11/2)		
20 (High)	15	32.4	486.6
45 (Mod.)	6	32.1	192.4
65 (Low)	6	27.4	153.5
Mean	9	30.6	271.7
SE[x]	6	1.5	ns

[z]Means of 5 trees/treatment.
[y]Range in dates of initiation.
[x]SE for comparison of means among growth flushes. Comparison among irrigation levels within growth flushes is inappropriate since irrigation x flush interaction is not significant.

shoots that initiated growth during the later flushes of the season. Perhaps the level of carbon reserves at the time of flush initiation affects the number of shoots that grow.

Average shoot length consistently increased with the three successive flushes during all years of the irrigation scheduling experiments, and shoot number generally decreased from flush one to flush three. This is consistent with previous studies with citrus growth and development in both subtropical and arid regions (Krishnamurthi et al., 1960; Mendel, 1969).

Final Measurements

Final canopy size was not different for trees in the high and moderate treatments in 1985 or 1986. The low treatment, however, significantly decreased canopy volume ($P<.0003$), trunk cross sectional area ($P<.0001$), dry weight ($P<.0043$), total shoot length ($P<.0040$), and leaf area ($P<.0029$) when compared to the high treatment in 1985 (Table 3-8). Similarly, in 1986 trees in the low treatment had significantly less canopy volume ($P<.0023$), trunk cross-sectional area ($P<.0017$), dry weight ($P<.0086$), and leaf area ($P<.0217$) than in the high treatment (Table 3-8).

Irrigation treatment effects on canopy growth followed a different pattern in 1987. Both the moderate and low treatments reduced tree growth measured as trunk cross sectional area ($P<.0029$), canopy dry weight ($P<.0050$), shoot length ($P<.0257$), and leaf area ($P<.0112$) when compared to the high treatment (Table 3-8). In addition, final canopy size for all treatments was generally smaller in 1987 when compared to the other years. This difference in growth response may be due to the nursery trees used in 1987. As

Table 3-8. Canopy volume, dry weight, shoot length, leaf area and trunk cross-sectional area of young 'Hamlin' orange trees as related to irrigation based on soil water depletion.

Soil water depletion (%)	Canopy volume (m^3)	Trunk cross sectional area (cm^2)	Canopy dry wt. (g)	Shoot length (cm)	Leaf area (m^2)
		<u>1985</u>			
20 (High)	0.57	5.1	424.6	950.8	1.3
45 (Mod.)	0.52	4.9	425.8	950.9	1.2
65 (Low)	0.33**	4.2**	336.6**	752.4**	1.0**
		<u>1986</u>			
20 (High)	0.51	8.0	379.2	950.4	1.3
45 (Mod.)	0.54	8.0	383.3	942.8	1.3
65 (Low)	0.31**	6.8**	300.0**	894.3	0.9**
		<u>1987</u>			
20 (High)	0.56	4.7	393.2	1428.6	1.4
45 (Mod.)	0.37	3.8*	259.0**	937.4*	0.7*
65 (Low)	0.36	3.3*	229.6**	872.2*	0.5*

*,**Response is significant when compared with the 20% soil water depletion treatment by the Williams' method, 5% and 1%, respectively.

discussed earlier, abscission of most leaves occurred shortly after transplanting to the field, inducing a flush with more than three times the number of shoots than occurred in 1985 or 1986. Newly-emerged shoot growth in citrus is mainly dependent upon stored reserves (Sinclair, 1984; Van Noort, 1969), and this heavy flush may have severely depleted the level of reserves in these trees. Webb (1981) stated that following a heavy defoliation of fir trees, recovery was related to the level of carbohydrate reserves in the trees, and trees with a low level of reserves died. Survival was not a problem in this study, but a severe depletion of reserves early in the spring may have caused reduced canopy growth in general in 1987, especially in the moderate and low treatments. Weak trees typically respond to more frequent irrigation with increased growth.

Seasonal Distribution of Shoot Growth

More than two-thirds of the trees in 1985 initiated their first growth flush the last week in May, and all had begun growth by 25 June (Fig. 3-7). Initiation of the second flush occurred from 12 July to 19 Aug.. Irrigation treatments did not affect the dates of initial growth in either of the first two flushes. Initiation of the third flush occurred over a longer time period than for flushes one and two. The entire population of trees receiving the high irrigation treatment had begun growth of flush three in October. The percentage of trees initiating this flush in the moderate and low treatments was shifted to later in the season, and approximately 40% of the trees in the low treatment did not initiate a third flush. The shapes of curves in flush three differed significantly among treatments.

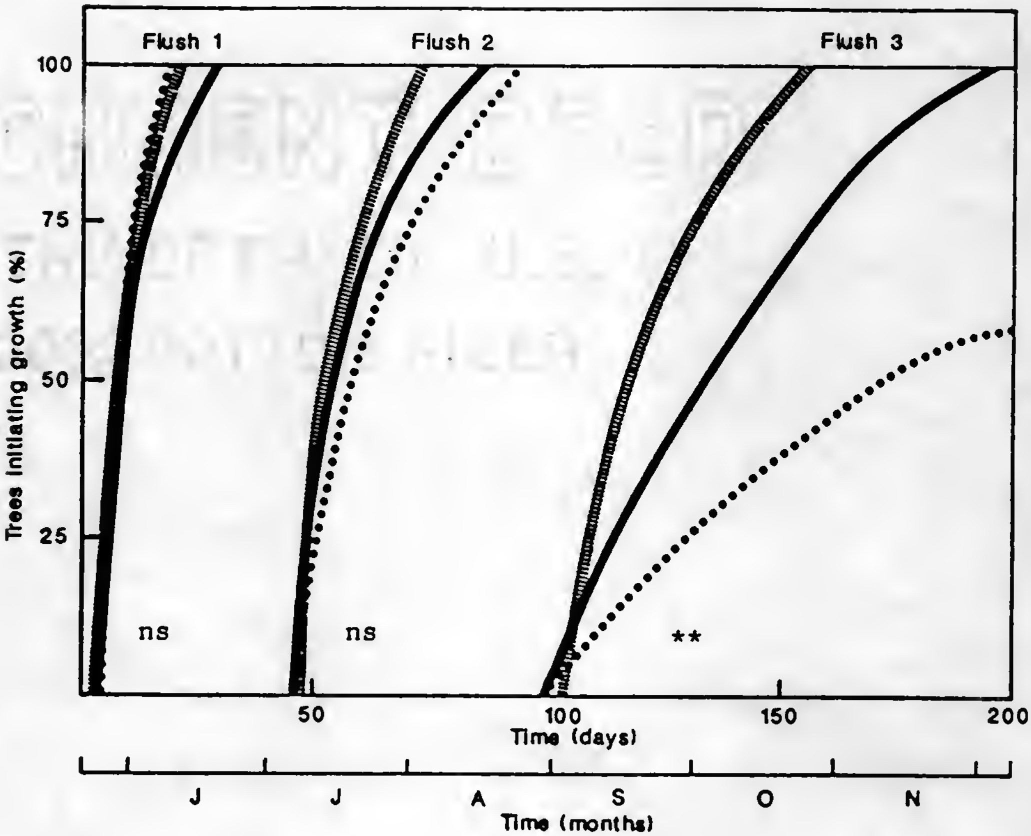

Fig. 3-7. Cumulative percentage of trees in three irrigation treatments growing over the 1985 season. (▪▪▪▪▪) = 20% soil water depletion (SWD), (▬▬) = 45% SWD, (•••••) = 65% SWD. ns,** indicates nonsignificance or significant at the 1% level, respectively, according to analysis of covariance test of homogeneity of the three equations.

Similarly, initiation of the first growth flush in 1986 was not affected by irrigation treatments, and occurred between 25 May and 17 June (Fig. 3-8). The two subsequent flushes were initiated over a longer time interval, ranging from 7 July to 13 Sept. in flush two and 30 Aug. and Dec. in flush three. The shapes of the curves in both flushes two and three differed significantly among treatments. Again, the percentage of trees initiating a flush in the moderate and low treatments shifted growth to later in the season compared to the high treatment. Approximately 25 and 35% of the trees in the moderate and low irrigation treatments had not initiated growth of the third flush by the end of the season.

Initiation of flush one in 1987 occurred earlier than in the other years due to an earlier planting date (Fig. 3-9). Trees across all treatments began growth between 12 April and 6 May. Flushes two and three were again spread over a longer time interval than flush one. Treatment effects were similar to those in 1986 in that the shapes of the curves for flushes two and three differed significantly. All trees initiated a third flush by the end of the season, in contrast to 1985 and 1986, possibly resulting from the earlier planting date.

Microsprinkler irrigation of these young trees at 45 and 65% SWD clearly prolonged the period between initiation of flushes two and three in some cases when compared to 20% SWD. Similarly, Cooper et al. (1969) stated that a prolonging of the period of quiescence between growth flushes of citrus commonly occurs in response to drought. This delay in shoot growth may result from decreased levels of available reserves, since a considerable reduction in CO_2

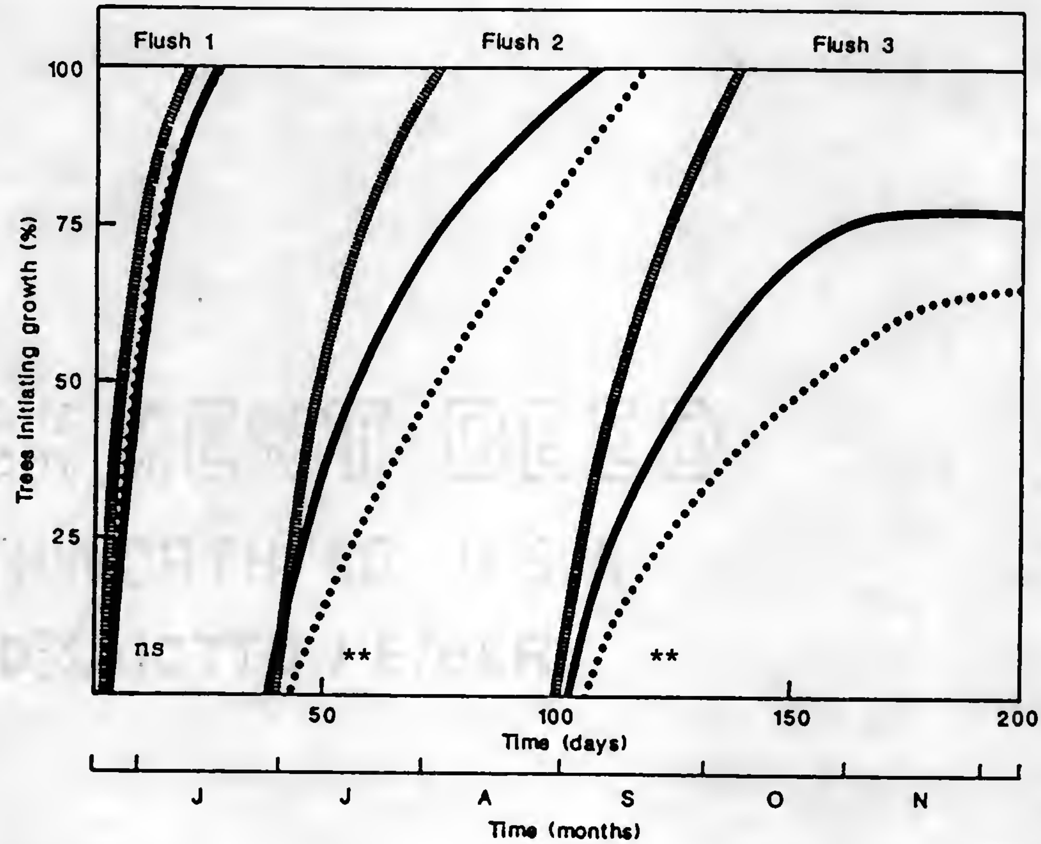

Fig. 3-8. Cumulative percentage of trees in three irrigation treatments growing over the 1986 season. (▬▬) = 20% soil water depletion (SWD), (▬▬) = 45% SWD, (•••••) = 65% SWD. ns,** indicates nonsignificance or significant at the 1% level, respectively, according to analysis of covariance test of homogeneity of the three equations.

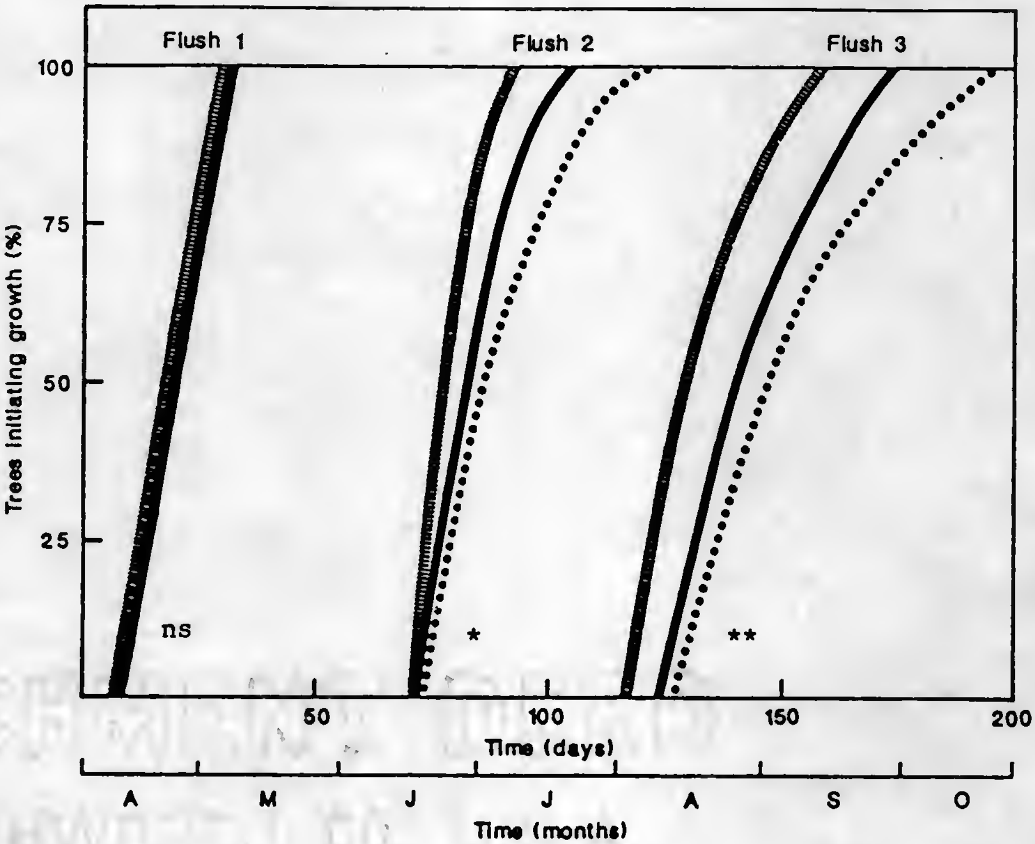

Fig. 3-9. Cumulative percentage of trees in three irrigation treatments growing over the 1987 season. (▬▬) = 20% soil water depletion (SWD), (▬▬) = 45% SWD, (•••••) = 65% SWD. ns,*,** indicates nonsignificance or significant at the 5 and 1% level, respectively, according to analysis of covariance test of homogeneity of the three equations.

assimilation occurred in response to increased soil water deficit (Chapter V). Perhaps a critical level of available reserves must be met before subsequent shoot growth begins. The period between flushes of citrus has been shortened with longer daylengths (Piringer et al., 1961). Both increased irrigation frequency and daylength would fit well into a hypothesis of available reserves controlling the length of time between flushes, as both would increase CO_2 assimilation over time. Shoot length and number of leaves per shoot are dependent upon available reserves before growth begins (Van Noort, 1969), and the date of growth may be dependent as well.

Other factors may be involved with this delay in growth. The amount of growth inhibitors reportedly decreases during the period between flushes (Mendel, 1969). It would be of value to understand the interactions of growth delays caused by less frequent irrigation with the levels of growth promoters and inhibitors. Knowledge of the interactions of root growth periodicity would also add understanding.

Time of shoot growth initiation was uniform from plant to plant in the spring flush all 3 years and across all irrigation treatments, but became more widespread in the subsequent flushes. This pattern has been previously documented with mature citrus trees in Australia (Sauer, 1951).

Microsprinkler Spray Patterns

Distributing irrigation water over 5.9 and 9.2 m^2 by using 90° and 180° spray patterns during the second growing season did not result in different trunk cross sectional area or canopy volume

(Figs. 3-10, -11). Furthermore, measurements of root distribution suggested that 90° emitters placed water over the majority of the citrus tree's root system after one season of growth (Chapter IV). When beginning with 90° spray patterns, there appears to be no advantage in changing to a larger pattern after the first season in the field. By directing more water on tree trunks, 90° patterns are more efficient than larger patterns for freeze protection purposes (Rieger et al., 1986). Maintaining 90° patterns for irrigation purposes more than one season allows their use throughout another winter for freeze protection.

In summary, growth of young 'Hamlin' orange trees was similar in 2 out of 3 years with the high (20% SWD) and moderate (45% SWD) irrigation treatments, but was reduced by the low treatment (65% SWD). The seasonal amount of water applied to the moderate treatment averaged about 50% of the amount applied to the high treatment. There was a pronounced delay in summer and fall growth flushes and in some cases a reduction in the number of shoots per tree in the low irrigation treatment.

The optimum level at which irrigations should be scheduled cannot be precisely determined from these studies, but is most likely between 20 and 45% SWD. These values are in general agreement with other reports. Smajstrla et al. (1985) obtained optimum growth of young 'Valencia' orange trees while scheduling irrigations at 45% SWD in a field lysimeter study. Leyden (1975a) presented no data, but suggested scheduling basin and strip watering methods of irrigation on 30% SWD, based on field observations. Therefore, it appears that on a per tree basis, microsprinkler

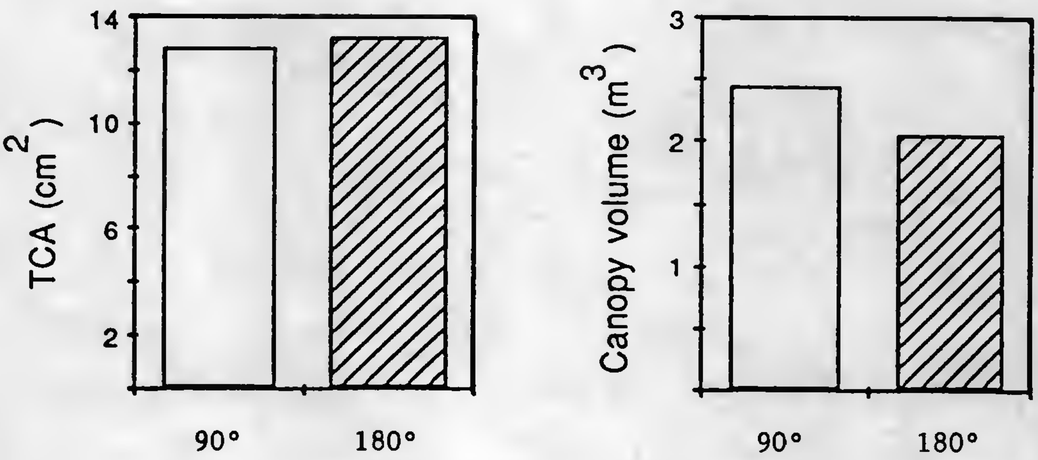

Fig. 3-10. Trunk cross sectional area (TCA) and canopy volume of young 'Hamlin' orange trees as influenced by microsprinkler irrigation spray pattern (90° and 180°), 1986. There were no significant differences between patterns, 5% level.

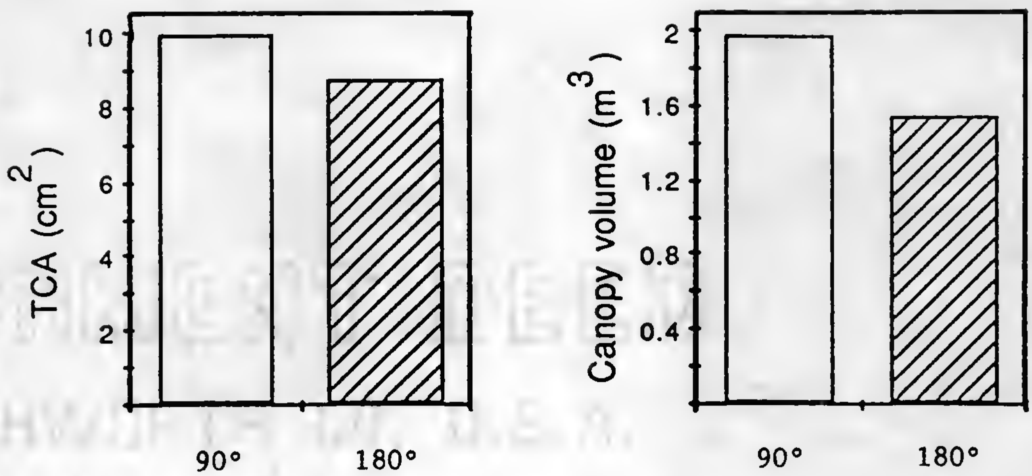

Fig. 3-11. Trunk cross sectional area (TCA) and canopy volume of young 'Hamlin' orange trees as influenced by microsprinkler irrigation spray pattern (90° and 180°), 1987. There were no significant differences between patterns, 5% level.

irrigation at 45% SWD is as effective as at 20% SWD, resulting in a considerable reduction in water use. However, on a population basis the final growth flush of some trees will be reduced at the moderate irrigation level probably because of inherent variability in SWD among trees within the treatment. Variability in soil moisture content is a particular problem in flatwoods areas of Florida where soil type is extremely variable. Consequently, growers must be certain to monitor soil moisture content carefully in a representative portion of their grove to ensure that the entire irrigated area receives adequate water.

CHAPTER IV

MICROSPRINKLER IRRIGATION AND GROWTH OF YOUNG 'HAMLIN' ORANGE TREES. II. ROOT GROWTH & DISTRIBUTION

Introduction

Perennial tree root systems respond to a variety of environmental and management factors, including irrigation. Irrigation method and scheduling directly affect soil water content and indirectly affect edaphic factors like physical impedence, fertility, and aeration, thus altering root growth and distribution. Increases in soil water content generally increase root growth provided that oxygen or salinity levels are not limiting. Irrigation has been observed to increase root growth or density of many crops (Goode et al., 1978; Goode & Hyrycz, 1970; Ponder & Kenworthy, 1976; Richards & Cockroft, 1975), including citrus (Bielorai, 1982; Bielorai et al., 1981; Bielorai et al., 1984; Hilgeman & Sharp, 1970; Rodney et al., 1977). In addition to growth responses, irrigation also affects root distribution. Frequent irrigation commonly increases the proportion of roots in shallow zones (Beukes, 1984; Cahoon et al.; 1961, Goode et al., 1978; Goode & Hyrcyz, 1964; Hilgeman et al., 1969; Hilgeman & Sharp, 1970; Layne et al., 1986; Levin et al., 1980).

Increasing demands on water resources require that irrigation be used more efficiently. Micro irrigation systems are becoming widely used in Florida, however, there is little information available on irrigation scheduling for young citrus trees under Florida's subtropical climate and sandy soil conditions. Therefore, our objectives were to study the influence of three microsprinkler irrigation treatments on root growth and distribution of young citrus trees.

Materials and Methods

Three field experiments were conducted at the Horticultural Research Unit near Gainesville, FL, with site and environmental variables as described in Chapter III. Microsprinkler irrigation was scheduled based on available soil water depletion (SWD) in the root zone. Treatments were defined as high (20% SWD), moderate (45% SWD), and low (65% SWD).

Root Growth and Lateral Distribution, Excavated Root Systems

Twenty, 21, and five root systems per treatment were excavated by hand in 1985, 1986, and 1987, respectively. Excavation procedure was described in Chapter III. Included in this group were samples of 10 (1985, 1986) and five (1987) randomly selected plants per treatment in which the root system was dyed prior to planting. Dyeing was accomplished by dipping roots for 15 sec in a 1% solution of safranin-O as described by Kaufmann (1968). Root dry weights were determined following oven-drying for 3 days at 80° C. Roots which had developed during the experimental period were easily distinguished from initial dyed roots, and were oven-dried and weighed separately. Random samples of 10 (1985, 1986) and five

(1987) plants per treatment were utilized to determine the increase in root volume. Water displaced by submersing root systems into water-filled containers was collected to determine root volume at planting time and after excavation.

Samples of 10 (1985) and five (1986, 1987) randomly selected, excavated root systems per treatment were used to determine lateral root distribution. After excavation these root systems were separated into three concentric zones (0-40, 40-80, and >80 cm) from the trunk. Distribution of total and fibrous ($\leq$ 1.5 mm) roots was determined on a dry weight and percentage basis.

Circular Trench Profiles

A modification of the trench profile method (Atkinson, 1980) for root distribution studies was used to determine irrigation effects on vertical root distribution at two distances from tree trunks. The method was modified by Huguet (1973) by using a curvilinear instead of a straight trench, based on the assumption that roots radiate concentrically from trunks. Based on the same assumption, circular trenches were dug by hand around each of three randomly selected trees per treatment in Dec. 1987. The initial trench was excavated 80 cm from the trunk to a depth of 50 cm. The profile was smoothed with a spade, then ca. 2 cm of soil was removed by hand with the aid of a brush to expose roots. It was not difficult to remove a 2 cm layer of soil from the circular profile walls due to the loose, sandy nature of the soil (Kanapaha sand). Roots were counted at each of four depth increments (0-10, 10-20, 20-30, and >30 cm) and categorized on the basis of total root number, and the number of fibrous ($\leq$ 1.5 mm) and non-fibrous (> 1.5

mm) roots. Vertical distribution was determined on a concentration (roots/m^2) and percentage basis.

Roots were counted to allow calculation of root length density immediately after recording root numbers. Lengths of exposed roots were estimated by visually counting the number of 2-cm sections of exposed root length as described previously (Bohm, 1976) in each depth increment. Roots that were perpendicular to the profile wall in situ extended ca. 2 cm, and were assigned a value of one, while roots longer than 2 cm were given values greater than one. For example, roots which were 3, 4, and 5 cm long were given values of 1.5, 2.0, and 2.5, respectively. Summation of these values estimated the number of 2-cm increments of exposed roots. Root length density (mm dm^{-3}) was determined for each depth by calculating total root length (multiplying the sum of all values by 2 cm) and volume of the 2 cm layer of soil on each profile wall. A second circular profile wall was subsequently exposed on the same tree at 40 cm from the trunk and the process repeated.

Analysis of Data

Data from excavated root systems were analyzed separately for the 3 years. Data on root dry weights were subjected to analysis of variance and data on root volumes to analysis of covariance to standardize initial root volumes. Where measurements were significantly different among irrigation treatments, Williams' (Williams, 1971) test was used to compare means.

Lateral distribution of total and fibrous ($\leq$ 1.5 mm) root dry weights were analyzed separately by a split-plot analysis with irrigation treatments as main plots and lateral zones as subplots.

Root percentage distribution among zones was analyzed in the same manner following arc sine transformation.

Measurements from profiles in 1987 of root density and root concentration of fibrous, non-fibrous, and total roots were analyzed separately. Percentage distribution data were transformed using an arc sine transformation prior to analysis. All data sets were analyzed by a split-split plot analysis with irrigation treatments as main plots, distance from the trunk as sub-plots, and depth increment as sub-sub-plots.

Results and Discussion

Root Weight and Volume Measurements

Irrigation treatments had variable effects on root dry weight and volume from year to year (Table 4-1). Dry weights were not affected in 1985, but root volume was decreased significantly at the low compared to the high irrigation treatment ($P<.0083$). Irrigation levels significantly affected root growth in 1986 and 1987. Trees receiving the low irrigation treatment in 1986 had less total root dry weight ($P<.0052$), new root dry weight ($P<.0249$), and root volume ($P<.0116$) than those in the high treatment. Both moderate and low treatments in 1987 decreased total root dry weight ($P<.0170$), new root dry weight ($P<.0455$), and root volume ($P<.0345$) compared to the high treatment.

Root volume ranged from 850 to 1190 cm^3 in 1985 and 1986, and from 550 to 860 cm^3 in 1987 (Table 4-1). Root dry weight ranged from 260 to 350 g in 1985 and 1986, and from 160 to 260 g in 1987. These values were in close agreement with those of Bevington (1983) and Bevington and Castle (1982) for 13-month-old 'Valencia' orange

Table 4-1. Total root dry weight, dry weight of new roots, and root volume of young 'Hamlin' orange/sour orange trees as related to irrigation based on soil water depletion.

Soil water depletion (%)	Total root dry wt (g)	New root dry wt (g)	Root volume (cm^3)
		1985 (n=20)	
20 (High)	348.7	156.3	1189.2
45 (Mod.)	333.9	158.8	1058.4
65 (Low)	297.3	139.4	920.5**
		1986 (n=21)	
20 (High)	342.1	191.0	1180.9
45 (Mod.)	337.8	185.4	1396.5
65 (Low)	262.1*	128.2*	854.3**
		1987 (n=5)	
20 (High)	257.8	126.2	858.2
45 (Mod.)	169.4*	84.8*	559.7*
65 (Low)	159.6*	81.2*	554.0*

*,** Response is significant when compared with the 20% SWD treatment by the Williams' method; 5% and 1% levels, respectively.

on 'Carrizo' citrange or rough lemon trees grown in root observation chambers. Tree age in this study was about 7 months in 1985 and 1986, and 8 months from planting in 1987. The comparable root sizes in the field and root chamber studies despite the much shorter growing period in the field study may be due to rootstock differences or to the allowance of unrestricted root development under the field conditions.

Shoot:root ratio was calculated using dry weight measurements reported in Chapter III (Table 3-8). The SWD ranges used in this study did not significantly influence shoot:root ratio, which ranged from 1.16 to 1.54, with a mean of 1.30. These values are lower than those reported for 1 1/2-year-old mandarin seedlings in India, where healthy trees had a shoot:root ratio of 1.92 (Aiyappa & Srivastava, 1965). Comparatively, excavated mature citrus trees in California had a ratio of about 3.5 (Cameron, 1939; Cameron & Compton, 1945), and in Florida a ratio of about 2.2 (Castle, 1978).

Root growth was less in 1987 compared to the other years despite a longer growing season. Furthermore, trees under moderate irrigation grew similarly to those in the high treatment in 1985 and 1986, but had less root growth than those in the high treatment in 1987. These discrepancies may be due to the nursery trees used in 1987. Excessive leaf abscission occurred shortly after transplanting trees to the field in 1987, inducing a growth flush with a large number of shoots per tree (Chapter III, Table 3-7). Such a growth flush early in the spring may have depleted available reserves thus decreasing subsequent root growth.

In all 3 years root growth was decreased at the lowest soil moisture content. Similarly, decreased root growth in response to decreased soil moisture has been frequently reported for citrus trees of various ages (Bevington & Castle, 1985; Bielorai, 1982; Bielorai et al., 1981; Hilgeman & Sharp, 1970; Rodney et al., 1977).

Lateral Root Distribution

Lateral distribution of roots on a dry weight basis was affected by irrigation treatments. The irrigation treatment x lateral zone interaction for total root weight was significant in 1985 ($P<.0238$), 1986 ($P<.0405$), and 1987 ($P<.0141$). A greater quantity of roots within 40 cm of the trunk occurred in response to the high treatment when compared to moderate and low treatments (Tables 4-2, -3, -4). Root weight in the 40-80 and >80 cm zones was not affected by irrigation, but in all 3 years the high treatment produced more roots than other treatments in the 0-40 cm zone. In contrast, irrigation treatments did not affect lateral distribution of fibrous ($\leq$1.5 mm) root dry weight or distribution of both fibrous and total roots on a percentage basis.

Across all irrigation treatments and years root dry weights and percentages decreased significantly ($P<.0001$) with increased distance from trunk (Tables 4-2, -3, -4). One exception occurred in 1986, when fibrous root weight was not different among the lateral zones (Table 4-3). The percentage of fibrous roots within 40 cm of the trunk ranged from 40 to 60%, between 40 and 80 cm from 26 to 39%, and >80 cm from 13 to 29%. A much larger percentage of total root weight was located close to the tree, with 68 to 84%, 11 to

Table 4-2. Lateral dry weight and percentage distribution of fibrous (≤1.5 mm) and total root systems of young 'Hamlin' orange/sour orange trees as related to irrigation based on soil water depletion (SWD), 1985.

Distance from trunk	Irrigation treatment								
	20% SWD		45% SWD		65% SWD				
	High		Mod		Low		Mean		
(cm)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	SE[z]
				Fibrous					
0-40	47.9	61.3	46.6	53.0	44.8	56.5	46.4	56.7	3.6
40-80	20.1	25.7	26.0	29.5	22.3	28.1	22.8	27.9	3.6
>80	10.2	13.0	15.4	17.5	12.2	15.4	12.6	15.4	3.6
Total	78.2		88.0		79.3		81.8		
SE[y]	--	--	--	--	--	--	5.9	7.0	
				Total roots					
0-40	292.0	83.9	257.3	80.0	256.3	82.0	269.0	82.0	10.4
40-80	40.0	11.5	44.9	13.9	40.6	13.0	41.9	12.8	10.4
>80	16.0	4.6	19.7	6.1	15.3	5.0	17.1	5.2	10.4
Total	348.0		321.9		312.2		328.0		
SE[y]	10.0	--	10.0	--	10.0	--		7.6	

[z]SE for comparison of irrigation treatment means within the same zone.
[y]SE for comparison of zone means within columns. Where no SE is given, comparison among zone means is inappropriate since irrigation x zone interaction is not significant.

Table 4-3. Lateral dry weight and percentage distribution of fibrous ($\leq$1.5 mm) and total root systems of young 'Hamlin' orange/sour orange trees as related to irrigation based on soil water depletion (SWD), 1986.

Distance from trunk	Irrigation treatment								
	20% SWD		45% SWD		65% SWD				
	High		Mod		Low		Mean		
(cm)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	SE[z]
				Fibrous					
0-40	40.2	40.3	32.4	40.3	27.0	40.1	33.2	40.2	7.9
40-80	31.2	30.7	26.6	33.1	27.4	38.8	28.4	34.2	7.9
>80	30.2	29.0	21.4	26.6	16.0	21.1	22.5	25.6	7.9
Total	101.6		80.4		70.4		84.1		
SE[y]	--	--	--	--	--	--	5.6	5.9	
				Total roots					
0-40	239.8	68.3	189.2	70.7	163.0	69.2	197.3	68.6	20.0
40-80	72.6	20.1	53.8	19.1	51.0	21.6	59.1	20.6	20.0
>80	44.0	11.6	27.4	10.2	21.6	9.2	31.0	10.8	20.0
Total	356.4		270.4		235.6		287.4		
SE[y]	13.1	--	13.1	--	13.1	--		4.7	

[z] SE for comparison of irrigation treatment means within the same zone.
[y] SE for comparison of zone means within columns. Where no SE is given, comparison among zone means is inappropriate since irrigation x zone interaction is not significant.

Table 4-4. Lateral dry weight and percentage distribution of fibrous ($\leq$1.5 mm) and total root systems of young 'Hamlin' orange/sour orange trees as related to irrigation based on soil water depletion (SWD), 1987.

Distance from trunk	Irrigation treatment								
	20% SWD		45% SWD		65% SWD				
	High		Mod		Low		Mean		
(cm)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	SE[z]
				Fibrous					
0-40	32.0	46.6	25.2	49.0	23.0	50.7	26.7	48.5	4.8
40-80	26.0	37.7	19.4	38.1	14.6	32.1	20.0	36.4	4.8
>80	10.4	15.7	6.8	12.9	7.8	17.2	8.3	15.1	4.8
Total	68.4		51.4		45.4		55.0		
SE[y]	--	--	--	--	--	--	7.8	13.9	
				Total roots					
0-40	197.0	76.4	132.6	78.3	124.8	78.0	151.5	77.5	15.3
40-80	44.0	17.1	28.2	16.6	26.0	16.4	32.7	16.7	15.3
>80	16.8	6.5	8.6	5.1	8.8	5.6	11.4	5.8	15.3
Total	257.8		169.4		156.4		195.6		
SE[y]	13.5	--	13.5	--	13.5	--		9.1	

[z]SE for comparison of irrigation treatment means within the same zone.
[y]SE for comparison of zone means within columns. Where no SE is given, comparison among zone means is inappropriate since irrigation x zone interaction is not significant.

21%, and 4 to 11% of root dry weight in the three concentric lateral zones, respectively.

The decrease in root growth with increasing distance from the trunk has been reported for citrus trees of all ages (Aiyappa & Srivastava, 1965; Bielorai, 1977, 1982; Bielorai et al., 1981; Cahoon et al., 1964; Minessy et al., 1971; Yagev & Choresh, 1974). Healthy 1 1/2-year-old mandarin trees in India had 60.0, 14.7, 13.2, and 12.1% of their root dry weight in 0-30, 30-60, 60-90, and >90 cm concentric zones, respectively (Aiyappa & Srivastava, 1965). These values are similar to those from the young 'Hamlin' orange trees in this study.

Maximum distance of lateral root spread pooled over the 3 seasons averaged 137 cm for the high treatment, compared with 127 for moderate and 121 cm for the low treatments, respectively (data not shown). In comparison, 2-year-old 'Valencia' orange trees in Australia had a lateral root spread of about 150 cm (Till & Cox, 1965), and 1 1/2-year-old mandarin trees in India had a spread of 160 cm (Aiyappa & Srivastava, 1965). Savage et al. (1945) observed that 6-year-old trees budded on common rootstocks and spaced 30 x 90 cm in a Florida nursery had lateral root spreads up to 150 cm.

There is considerable discussion about the optimum irrigation pattern to use for young citrus trees in Florida. Roots covered an area of about 5.2 m^2, with 64% of this area covered by the 90° emitters in this study. Furthermore, 96% of the roots on a dry weight basis were within the wetted zones due to the high concentration of roots within 80 cm of the trunk (Tables 4-2, -3, -4). These data imply that 90° microsprinkler emitters cover the

majority of the young tree's roots after one season of growth. Tree growth comparisons utilizing 90° and 180° emitters during the second season of growth also suggest 90° emitters are adequate for up to 2 years in the field (Figs. 3-10, -11).

Weight of fibrous roots accounted for 27% of the total. This value is similar to those found on root systems of rough lemon and 'Carrizo' citrange in the nursery (Bevington & Castle, 1982), but considerably less than found on healthy 1 1/2-year-old mandarin seedlings (37.5%) growing in India (Aiyappa & Srivastava, 1965). In comparison, feeder roots on 8- to 9-year-old orange trees on sweet orange rootstock accounted for less than 15% of the root system dry weight (Cameron & Compton, 1945).

Circular Trench Profiles

Analysis of variance results showing effects of irrigation treatments, distance from tree trunks, and depth increments on root density (mm dm^{-3}) and concentration (roots m^{-2}) of total, fibrous, and non-fibrous roots are summarized in Table 4-5. A larger proportional increase in total root concentration occurred at 40 than at 80 cm from the trunk in response to the high treatment (Table 4-6). This corroborates results of irrigation treatment effects on lateral root dry weight distribution (Tables 4-2, -3, -4). The high irrigation treatment produced a proportionally larger increase in root number in the 10-20 cm layer than in the other layers (Table 4-6). The greatest number of roots grew in this layer, regardless of irrigation treatment and there was little root growth in the 0-10 cm depth regardless of treatment, and trees under the high treatment had the highest root concentration at all depths

Table 4-5. Partitioning of variance into main and interaction effects for 1987 circular trench profile root growth variables of 'Hamlin' orange trees as described in Tables 4-6, 4-7, and 4-8.

		F tests on variance (MS) ratios			
Source	df	Total root conc.	Fibrous root conc.	Non-fibrous root conc.	Total root density
Irrigation (I)	2	5.39^{*}	6.05^{*}	1.10^{ns}	5.73^{*}
Distance (Di)	1	55.40^{***}	54.88^{***}	44.03^{***}	55.60^{***}
I x Di	2	5.90^{*}	6.40^{*}	1.55^{ns}	6.10^{*}
Depth (De)	3	60.12^{***}	60.08^{***}	38.06^{***}	58.58^{***}
I x De	6	5.76^{**}	6.11^{**}	1.71^{ns}	5.32^{**}
Di x De	3	21.61^{***}	21.35^{***}	15.79^{***}	19.91^{***}
I x Di x De	6	2.27^{ns}	2.43^{ns}	0.92^{ns}	2.21^{ns}

^{ns,*,**,***} Nonsignificant or significant F values at the 5%, 1%, and .1% levels, respectively.

Table 4-6. Total root concentration at four depths and two distances from trunk of young 'Hamlin' orange/sour orange trees as influenced by irrigation based on soil water depletion (SWD) as determined using circular trench profiles, 1987.

Depth (cm)	Irrigation treatment 20% SWD High	45% SWD Mod.	65% SWD Low	Mean
	Root conc. (roots m^{-2}) at 40 cm[z]			
0-10	19.9	37.2	11.9	23.0
10-20	965.5	655.2	299.7	640.1
20-30	447.0	244.0	202.9	298.0
>30	291.8	156.5	70.3	172.9
Mean	431.1	273.2	146.2	283.5[y]
	Root conc. (roots m^{-2}) at 80 cm[z]			
0-10	13.9	6.6	0	6.8
10-20	215.5	222.8	45.1	161.1
20-30	159.1	172.4	87.5	139.7
>30	65.7	24.6	43.1	44.5
Mean	113.6	106.6	43.9	88.0[y]

[z]n=3 for irrigation x distance x depth means.
[y]Mean for distance from trunk.

below 10 cm. This increase in root concentration in response to maintaining higher soil moisture levels corroborates the dry weight measurements made on excavated root systems (Table 4-1).

The concentration of fibrous roots ($\leq$1.5 mm) followed patterns similar to total root concentration in regard to irrigation treatments, distance from trunk, and depth because fibrous roots comprised the majority of the total roots (Table 4-7). Differences in non-fibrous (>1.5 mm) root concentration were not associated with irrigation treatments. There were four times as many large roots at 40 cm from tree trunks than 80 cm, and almost half were located between 10 and 20 cm in depth (Table 4-8). Trees receiving the low irrigation treatment had 10 times as many fibrous as large roots; whereas, trees in the high and moderate treatments developed approximately 15 times the number of fibrous as large roots.

The percentages presented in Table 4-9 were pooled over the two lateral distances since they did not interact with percentage distribution with depth. Greater than 50% of the root concentration was between 0-20 cm with high and moderate irrigation, but was deeper than 20 cm with low irrigation. Because of the small number of replications and the variability, this difference was not enough to be significant. Across all treatments, percentages of roots were significantly ($P<.0001$) different with depth (Table 4-9). Roughly half of the roots were 10-20 cm deep, with 35% between 20-30 cm, and less than 15% below 30 cm. More than 85% of the roots were located between 0-30 cm in depth.

The concentration of roots in the top 30 cm after 1 season of growth suggests that when soil moisture monitoring is used for

Table 4-7. Concentration of fibrous (≤1.5 mm) roots at four depths and two distances from trunk of young 'Hamlin' orange/sour orange trees as influenced by irrigation based on soil water depletion (SWD) as determined using circular trench profiles, 1987.

Depth	Irrigation treatment 20% SWD	45% SWD	65% SWD	
(cm)	High	Mod.	Low	Mean
	Root conc. (roots m^{-2}) at 40 cm[z]			
0-10	19.9	33.2	11.9	21.7
10-20	903.2	614.1	263.9	593.7
20-30	415.1	228.1	181.7	275.0
>30	279.9	149.9	65.0	164.9
Mean	404.5	256.3	130.6	263.8[y]
	Root conc. (roots m^{-2}) at 80 cm[z]			
0-10	13.3	6.0	0	6.4
10-20	199.6	211.5	43.1	151.4
20-30	150.5	157.8	84.9	131.1
>30	63.0	23.9	41.8	42.9
Mean	106.6	99.8	42.5	83.0[y]

[z] n=3 for irrigation x distance x depth means.
[y] Mean for distance from trunk.

Table 4-8. Concentration of non-fibrous (>1.5 mm) roots at four depths and two distances from trunk of young 'Hamlin' orange/sour orange trees as influenced by irrigation based on soil water depletion (SWD) as determined using circular trench profiles, 1987.

	Irrigation treatment			
Depth	20% SWD	45% SWD	65% SWD	
(cm)	High	Mod.	Low	Mean
	Root conc. (roots m^{-2}) at 40 cm[z]			
0-10	0	4.0	0	1.3
10-20	62.3	41.1	35.8	46.4
20-30	31.8	15.9	21.2	23.0
>30	11.9	6.7	5.3	8.0
Mean	26.5	16.9	15.6	19.7[y]
	Root conc. (roots m^{-2}) at 80 cm[z]			
0-10	0.7	0.7	0	0.5
10-20	15.9	11.3	2.0	9.7
20-30	8.6	14.6	2.7	8.6
>30	2.7	0.7	1.3	1.6
Mean	7.0	6.8	1.5	5.1[y]

[z] n=3 for irrigation x distance x depth means.
[y] Mean for distance from trunk.

Table 4-9. Percentage distribution of root concentration with depth of young 'Hamlin' orange/sour orange trees as influenced by irrigation based on soil water depletion (SWD). Percentages are means of measurements from 40 and 80 cm distances from trunk, 1987.

	Irrigation treatment			
Depth	20% SWD	45% SWD	65% SWD	
(cm)	High	Mod.	Low	Mean
		<1.5 mm		
0-10	1.4	2.6	1.6	1.8
10-20	47.9	57.2	38.0	47.7
20-30	34.1	30.6	41.4	35.4
>30	16.6	9.6	19.0	15.1
		>1.5 mm		
0-10	0.6	3.1	0	1.2
10-20	50.8	48.4	45.2	48.2
20-30	36.3	38.9	38.5	37.9
>30	12.3	9.6	16.3	12.7
		Total		
0-10	1.3	2.7	1.4	1.8
10-20	48.1	56.5	38.4	47.7
20-30	34.2	31.3	41.6	35.7
>30	16.4	9.5	18.6	14.8

irrigation scheduling, measurements should be concentrated in this zone. Furthermore, irrigation times should be limited to replenish soil moisture only in these shallow zones. Irrigations of short duration are adequate when using systems which direct applications to a small areas on sandy soils. Soil moisture was monitored at a depth of 30 cm in this study, and at 20% SWD the 90°, 38 liter/hr emitters required approximately 1 hr to replenish the root zone to field capacity.

Root length density (mm dm^{-3}) at two distances from tree trunks and four soil depths as influenced by irrigation treatment followed patterns similar to root concentrations. The greatest difference between treatments occurred between 10-20 cm, with differences of less magnitude deeper in the profile (Table 4-10). Densities ranged from 0.5 mm dm^{-3} at 80 cm from the trunk on trees under the low irrigation treatment to 9.8 mm dm^{-3} at 40 cm from the trunk on trees under the high irrigation treatment.

Mature citrus responded to frequent irrigation with an increased proportion of roots in shallow root zones and a decrease in root growth in deep root zones using flood (Cahoon et al., 1961; Cahoon et al., 1964; Hilgeman & Sharp, 1970) and drip (Ruggiero & Andiloro, 1984) irrigation systems. Results from this study indicated that irrigating more often in the high treatment had no effect on root growth in the 0-10 cm depth, and increased the proportion of root growth in the 10-20 cm depth compared to deeper zones. However, in contrast to the previous studies, there was no decrease in root concentration or length density in the deeper zones with the frequent irrigation. These results are similar to those

Table 4-10. Root length density at four depths and two distances from trunk of young 'Hamlin' orange/sour orange trees as related to irrigation based on soil water depletion (SWD) as determined using circular trench profiles, 1987.

	Irrigation treatment			
Depth	20% SWD	45% SWD	65% SWD	
(cm)	High	Mod.	Low	Mean
		Density (mm dm^{-3}) at 40 cm^z		
0-10	0.2	0.4	0.1	0.2
10-20	9.8	6.7	3.1	6.5
20-30	4.9	2.7	2.2	3.3
>30	3.5	1.9	0.9	2.1
Mean	4.6	2.9	1.6	3.0^y
		Density (mm dm^{-3}) at 80 cm^z		
0-10	0.1	0.1	0	0.1
10-20	2.2	2.3	0.6	1.7
20-30	1.8	1.9	1.0	1.5
>30	0.8	0.3	0.5	0.5
Mean	1.2	1.2	0.5	1.0^y

^{z}n=3 for irrigation x distance x depth means.
^{y}Mean for distance from trunk.

found when mature citrus trees were irrigated at different rates, scheduled at the same frequency (Bielorai et al., 1981; Bielorai et al., 1984). Differences in soil characteristics, amount of rainfall, and other growing conditions certainly interact with tree root system responses to irrigation.

Observations on the spatial distribution of roots along the exposed circular profile walls indicated that partial sampling techniques such as partial excavation or core sampling could have led to inaccurate results if they were used. Variability within the volume of soil encompassing a root system is a widespread problem for root investigators (Atkinson, 1980). The use of total excavation and circular trench profiles helped minimize this variability in our measurements.

In summary, the high irrigation treatment increased root growth and proportionally increased growth near the trunk, based on root dry weight, concentration, and length density. There was little root growth between 0-10 cm in depth regardless of irrigation treatment. The greatest response occurred between 10-20 cm in depth, where the high treatment increased root number and length when compared to the moderate and low treatments, but root growth was increased even in deeper root zones by the high treatment. More than 85% of the root growth was in the top 30 cm of soil, concentrated almost entirely between 10 and 30 cm. The 90° microsprinkler emitters covered 64% of the maximum root lateral spread, but greater than 90% of the roots (dry weight basis) were within the wetted zones.

Knowledge of the root distribution of young citrus trees is useful in management decisions concerning microsprinkler irrigation patterns and times, and placement of sensors for monitoring soil moisture depletion. High rainfall during the summer months in Florida moderates plant responses to field irrigation treatments and may account for any contrast between some of our findings and root distribution data from other areas.

CHAPTER V

SOIL MOISTURE STRESS AND LEAF GAS EXCHANGE OF YOUNG, FIELD-GROWN 'HAMLIN' ORANGE TREES

Introduction

Transpiration, stomatal conductance, and CO_2 assimilation of citrus trees are affected by soil moisture content. Decreases in soil moisture reduced CO_2 assimilation of young, containerized citrus trees under controlled conditions (Bielorai & Mendel, 1969; Brakke et al., 1986; Kriedemann, 1968, 1971; Ono & Hirose, 1984; Thompson et al., 1968) and transpiration or stomatal conductance of various-aged citrus trees under field and controlled conditions (Bielorai & Mendel, 1969; Brakke et al., 1986; Cohen & Cohen, 1983; Hilgeman, 1977; Kaufmann & Levy, 1976; Koo, 1953; Kriedemann, 1971; Ruggiero & Andiloro, 1985; Thompson et al., 1968; Zekri, 1984). There are few studies, however, concerning soil moisture effects on CO_2 assimilation of citrus under field conditions.

Soil water deficits may influence gas exchange processes in a number of ways. Stomatal closure in response to limited water availability may arise from a decrease in leaf water status or from non-hydraulic signals from roots (Blackman & Davies, 1985 a,b). Reduced stomatal conductance in turn may limit transpiration and CO_2 assimilation. In addition, CO_2 assimilation may be reduced by soil

water deficits via direct reduction of dark and light reactions or residual conductance to CO_2.

This work was undertaken to provide information on the effect of soil water deficit on CO_2 assimilation, transpiration, stomatal conductance, xylem potential, and leaf temperature of young 'Hamlin' orange trees under field conditions in Florida.

Materials and Methods

Plant Material and Treatments

Commercially obtained, bare-rooted 'Hamlin' orange [*Citrus sinensis* L. (Osb.)] on sour orange (*C. aurantium* L.) trees were planted on beds (16.75 m width x 0.60-0.75 m height x 85 m length) at the Horticultural Unit northwest of Gainesville, Florida. Two tree rows 7.6 m apart were used per bed with trees spaced 4 m within rows. Site characteristics were as described in Chapter III. Soil water content was maintained between field capacity and 20% soil water depletion (SWD) of available soil water for high irrigation treatment, 45% SWD for the moderate treatment, and 65% SWD for the low treatment.

Leaf Measurements

The diurnal pattern of leaf gas exchange was determined on 18 October 1986 on trees planted 3-4 May 1986. Gas exchange fluxes are dependent on leaf age in citrus (Erickson, 1968; Kriedemann, 1971; Ono & Hirose, 1984; Syvertsen, 1982; Syvertsen et al., 1981), thus only shoots initiated during the week of 13-20 Sept. were chosen, which standardized leaf age. Preliminary data showed little variation in gas exchange measurements within an irrigation treatment both within trees and between trees. As a result, leaves

from the middle of two shoots on each of four trees per irrigation treatment were used, which assured completion of all measurements for a given time period within 30 min. Net CO_2 assimilation (A) was monitored with an Analytical Development Corporation (Hoddesdon, England) portable, open-system infrared analyzer (Model LCA-2) equipped with a Parkinson broadleaf leaf chamber (aperture = 6.25 cm^2). Outside air was supplied to the chamber at a flow rate of 400 cm^3/min, and A was calculated as described previously (Jarvis & Catsky, 1971). After all CO_2 assimilation measurements were completed, transpiration (E) and stomatal conductance (g_s) were determined on the same leaves using a LI-COR 1600 steady-state diffusion porometer.

The diurnal pattern of leaf temperature, gas exchange, and internal CO_2 concentration (C_i) was determined on 12, 13, and 15 June 1987 on fully-expanded spring flush leaves of trees planted 2 April 1987. Sample size was the same as in 1986, and shoots initiating growth during the week of 23-30 April were chosen. Net CO_2 assimilation, E, g_s, C_i, and leaf temperature were monitored with the Analytical Development Corporation instrumentation fitted with a data processor. All adjustments and calculations on measurements were made by the data processor as described previously (Jarvis & Catsky, 1971). Instantaneous water use efficiency (WUE) was calculated as A/E.

Leaf xylem potential was determined on 15 June 1987 using the Scholander pressure chamber technique (Scholander et al., 1965). One leaf from each of eight plants per treatment (based on variation

in preliminary measurements) was excised and placed immediately in the chamber for measurement.

Means and standard errors were calculated for trees in each irrigation treatment throughout photoperiods.

Environmental Measurements

Photosynthetic photon flux (PPF) and air temperature were determined with the Analytical Development Corporation instrumentation. Leaf to air temperature difference during June 1987 measurements was calculated by difference. Relative humidity was monitored with a hygrothermograph (WEATHERtronics Model 5021) located on the experimental site and vapor pressure deficit (VPD) was calculated from relative humidity and air temperature. Soil temperature at a 10 cm depth was monitored with a mercury thermometer. Mean midday level of soil water depletion for trees in each treatment was measured using the neutron scattering method.

Results and Discussion

Photosynthetic photon flux gradually increased to a peak of ca. 1500 μmol s^{-1} m^{-2} around 1200 hr on 18 Oct. 1986, and gradually decreased thereafter (Fig. 5-1a). Early morning air temperature was approximately 15° C, and a broad midday maximum of 25° C occurred before declining after 1700 hr (Fig. 5-1b). Relative humidity declined to a midday minimum below 50% and VPD increased to 2 kPa (Fig. 5-1 c,d). Soil temperature was 22° C initially and increased slowly to 24° C by 1400 hr (data not shown). Trees in the high treatment were irrigated on 17 Oct., and the soil was at field capacity on 18 Oct. in this treatment. The average midday SWD was

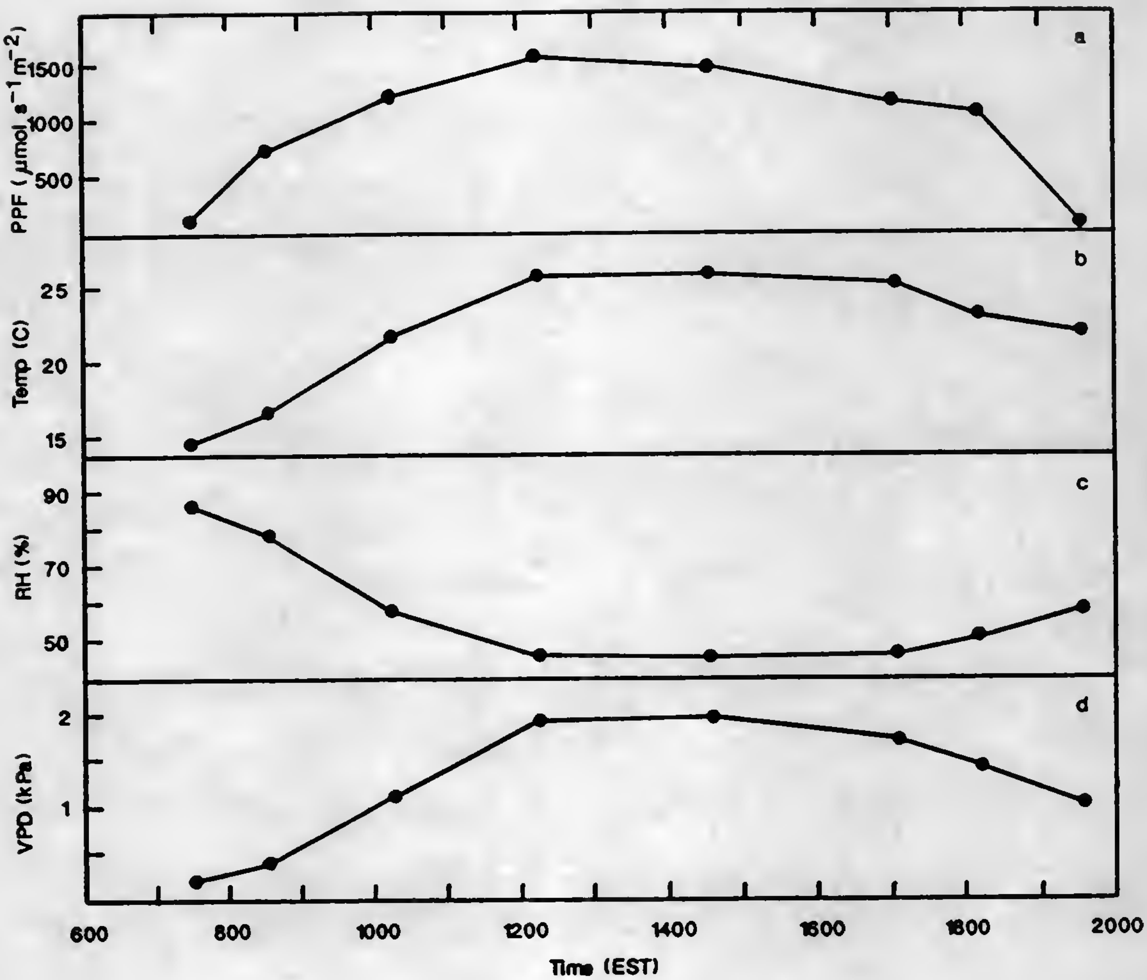

Fig. 5-1. Diurnal cycle of photosynthetic photon flux (PPF), air temperature, relative humidity (RH), and vapor pressure deficit (VPD) on 18 Oct. 1986.

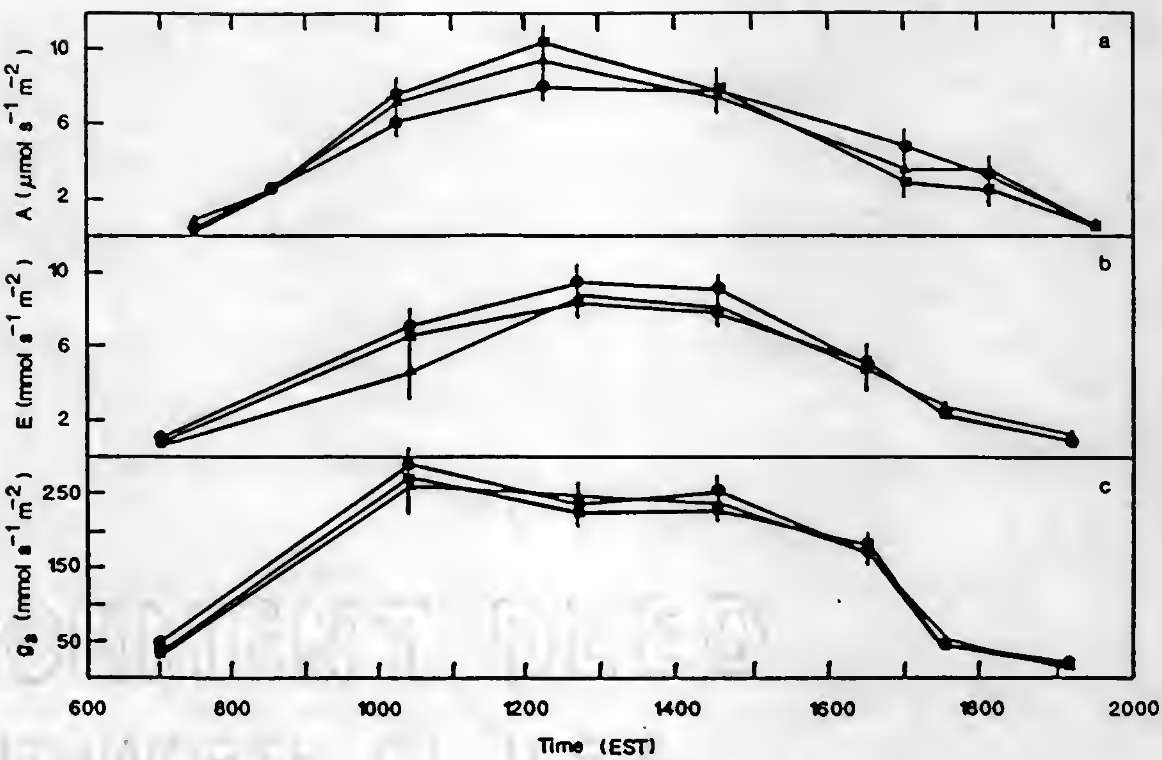

Fig. 5-2. Diurnal cycle of leaf CO_2 assimilation (A), transpiration (E), and stomatal conductance (g_s) of young 'Hamlin' orange trees on 18 Oct. 1986 as influenced by soil water depletion (SWD). (▲) = high treatment at field capacity, (●) = moderate treatment at 39% SWD, (■) = low treatment at 42% SWD. Bars represent SE of means, n=8.

39 and 42% for the moderate and low treatments, respectively (Table 5-1).

Diurnal patterns of leaf gas exchange on 18 Oct. 1986 were similar to PPF, temperature, and VPD (Fig. 5-2). Maximum CO_2 assimilation was above 9 μmol s^{-1} m^{-2}, and maximum E and g_s were 8.9 and 275 mmol s^{-1} m^{-2}. There was no consistent influence of SWD on A, E, or g_s, and little or no differences occurred between treatments during this time of cool temperatures (Fig. 5-2, Table 5-1). Diurnal variation of A was similar to that of mature, field-grown grapefruit on days characterized by mild VPD as described by Sinclair and Allen (1982). Transpiration of well-watered containerized sour orange and sweet lime seedlings also followed patterns similar to those reported here (Bielorai & Mendel, 1969).

Relative humidity averaged 90% in the early morning, accompanied by 25-26° C air temperature during 12, 13, and 15 June (Figs. 5-3b,c; -5b,c; -7b,c). Mid-afternoon air temperatures were above 35° C, accompanied by minimum relative humidity of below 50%. Photosynthetic photon flux was above 1700 μmol s^{-1} m^{-2} by mid-morning and remained high throughout the rest of the measurement period (Figs. 5-3a, -5a, -7a). Vapor pressure deficit remained high throughout midday, with maximum values of 2.5-3.0 kPa (Figs. 5-3d, -5d, -7d). Soil temperature was 28-29° C initially and stabilized at 30-31° C by 1300 hr (data not shown).

Trees in the high irrigation treatment had gone through nine drying cycles from field capacity to 20% SWD, while trees in the moderate treatment had gone through four drying cycles from field

Table 5-1. Mean and maximum leaf CO_2 assimilation, transpiration, and stomatal conductance of young 'Hamlin' orange trees on 18 Oct. 1986 as influenced by soil water depletion.

Soil water depletion (%)	CO_2 assimilation (μmol s^{-1} m^{-2})		Transpiration (mmol s^{-1} m^{-2})		Stomatal conductance (mmol s^{-1} m^{-2})	
	max.	mean	max.	mean	max.	mean
0^z	9.5	4.5	8.7	4.3	267	151
39	8.0	4.2	9.5	4.9	289	154
42	10.2	4.3	8.5	4.5	270	149

^{z}Midday mean soil water depletion level of high, moderate, and low irrigation treatments.

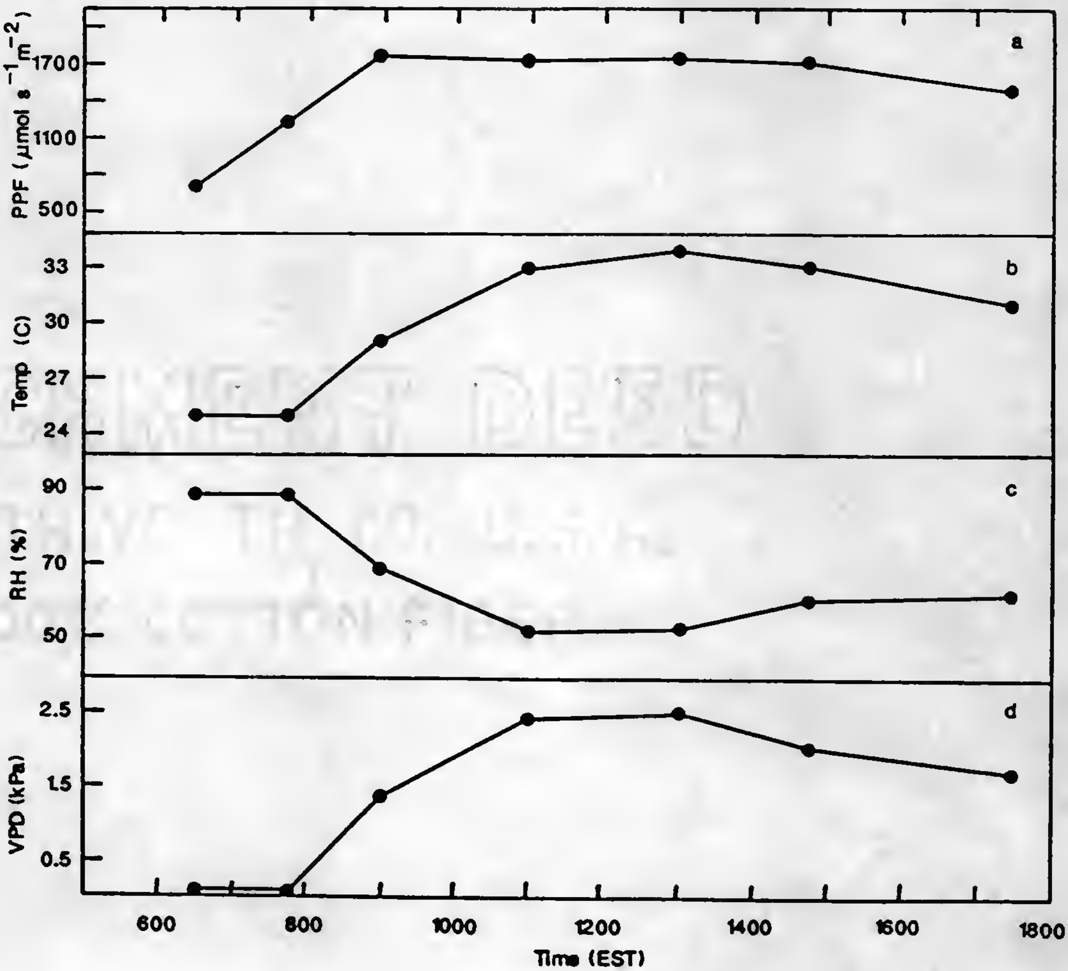

Fig. 5-3. Diurnal cycle of photosynthetic photon flux (PPF), air temperature, relative humidity (RH), and vapor pressure deficit (VPD) on 12 June 1987.

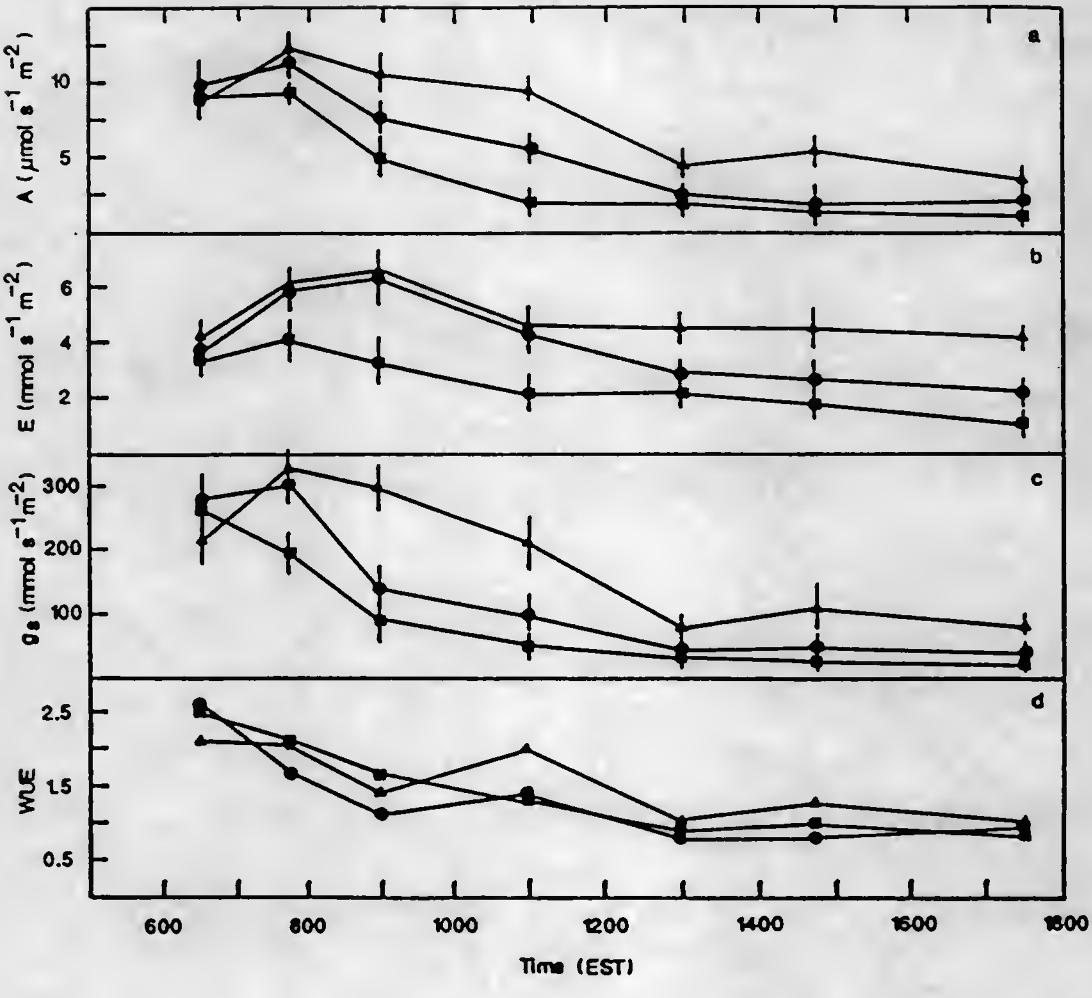

Fig. 5-4. Diurnal cycle of leaf CO_2 assimilation (A), transpiration (E), stomatal conductance (g_s), and water use efficiency (WUE) of young 'Hamlin' orange trees on 12 June 1987 as influenced by soil water depletion (SWD). (▲) = high treatment 19% SWD, (●) = moderate treatment at 28% SWD, (■) = low treatment at 53% SWD. Bars represent SE of means, n=8.

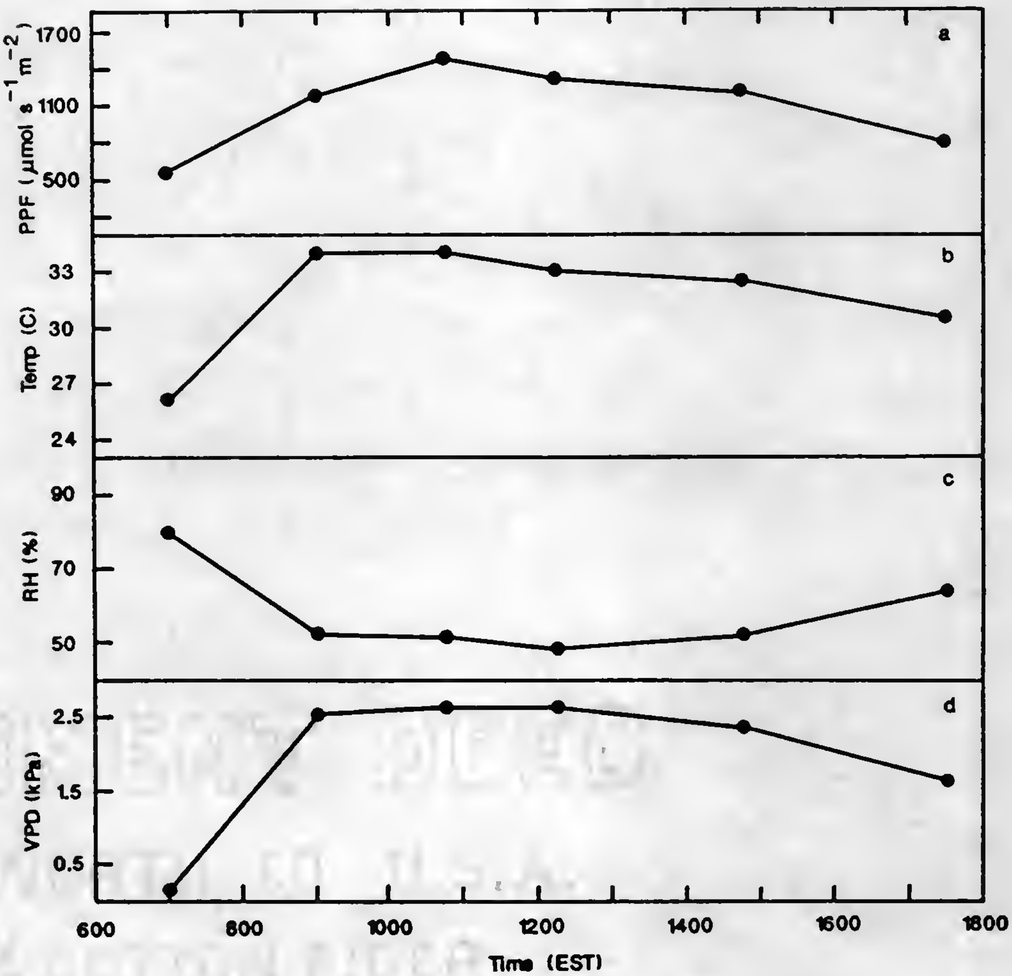

Fig. 5-5. Diurnal cycle of photosynthetic photon flux (PPF), air temperature, relative humidity (RH), and vapor pressure deficit (VPD) on 13 June 1987.

capacity to 45% SWD. Cumulative rainfall of 11.3 cm on 9 days had interrupted the drying cycles so that the predetermined level of 65% SWD for trees in the low treatment had never been reached. Dates of last irrigation were 9 June for the moderate and 13 April for the low scheduling treatments. Trees in the high treatment were irrigated 12 June following diurnal measurements, thus SWD was near 20% on 12 and 15 June, and 2% on 13 June following the irrigation (Table 5-2). Soil water depletion declined from 28% on 12 June to 45% on 15 June in the moderate treatment, and from 53% to 60% in the low treatment (Table 5-2).

Maximum CO_2 assimilation occurred from 700-800 hr on 12, 13, and 15 June (Figs. 5-4a, -6a, -8b). Maximum daily values were quite consistent through the 3 days, with trees in the high treatment averaging 12.5, moderate treatment, 11.4, and low treatment, 9.2 $\mu mol\ s^{-1}\ m^{-2}$ (Table 5-2). A gradual decline in CO_2 assimilation occurred throughout the day, with a partial recovery in midafternoon with trees in the high treatment. The reduction in A was more marked at the lower levels of soil moisture, and no recovery occurred in the afternoon. Carbon assimilation was averaged over all measurements (Table 5-2), and mean levels for the moderate and low treatments were 68 and 42% of those recorded for the high treatment. Mean daily CO_2 assimilation fell gradually from 12 to 15 June in the moderate and low treatments.

Maximum CO_2 assimilation recorded under these conditions was much higher than reported under greenhouse conditions of containerized sour orange and sweet lime (Bielorai & Mendel, 1969), rough lemon (Thompson et al., 1965), sweet orange (Kriedemann, 1971)

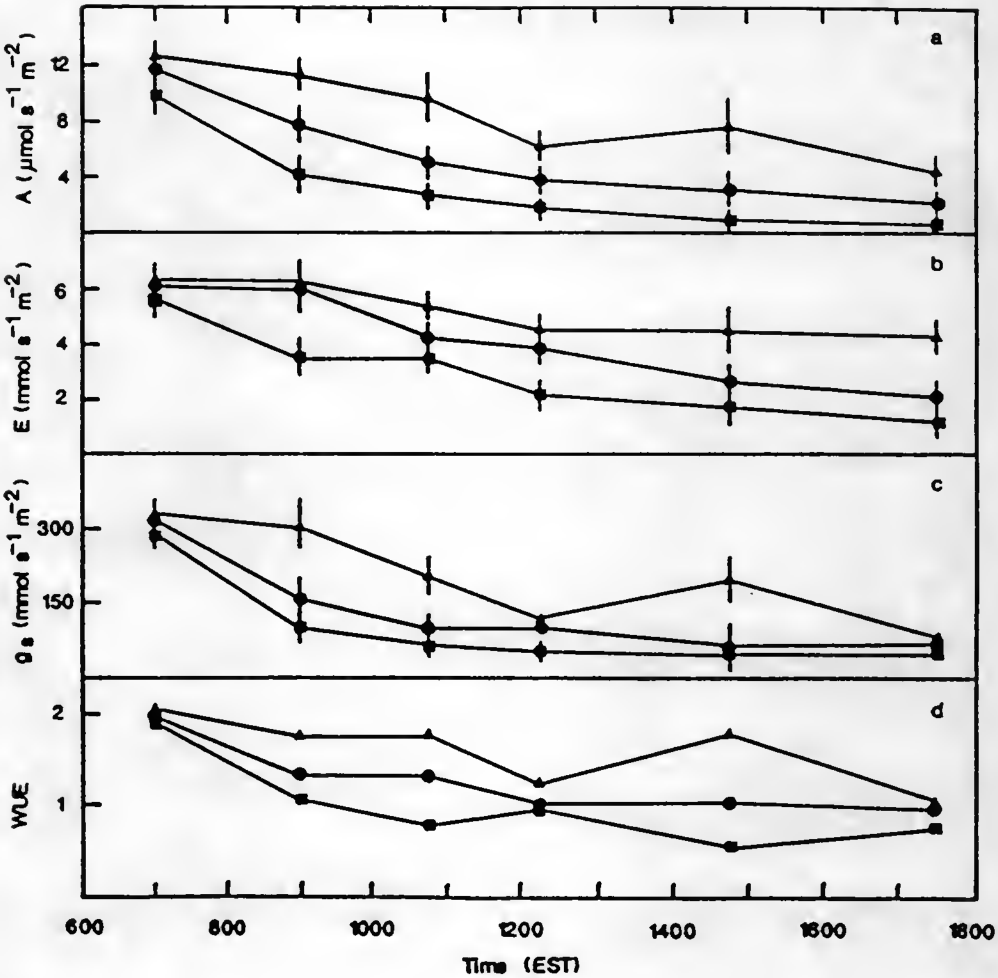

Fig. 5-6. Diurnal cycle of leaf CO_2 assimilation (A), transpiration (E), stomatal conductance (g_s), and water use efficiency (WUE) of young 'Hamlin' orange trees on 13 June 1987 as influenced by soil water depletion (SWD). (▲) = high treatment 2% SWD, (●) = moderate treatment at 32% SWD, (■) = low treatment at 55% SWD. Bars represent SE of means, n=8.

Table 5-2. Mean and maximum leaf CO_2 assimilation, transpiration, stomatal conductance, and mean internal CO_2 concentration (C_i) of young 'Hamlin' orange trees in June 1987 as influenced by soil water depletion.

Soil water depletion (%)	CO_2 assimilation (μmol s^{-1} m^{-2})		Transpiration (mmol s^{-1} m^{-2})		Stomatal conductance (mmol s^{-1} m^{-2})		Mean C_i (μl $liter^{-1}$)
	max.	mean	max.	mean	max.	mean	
				12 June 1987			
19[z]	12.5	8.2	6.7	5.0	325	189	226
28	11.5	6.0	6.6	4.2	305	136	232
53	9.4	4.5	4.1	2.7	259	99	234
				13 June 1987			
2	12.7	8.5	6.3	5.2	325	201	220
32	11.8	5.7	6.1	4.2	320	125	230
55	10.1	3.4	5.5	2.9	280	91	247
				15 June 1987			
20	12.4	7.6	6.2	4.6	316	154	223
45	11.0	4.7	5.7	3.5	306	105	231
60	8.1	2.4	4.1	1.8	181	54	250

[z]Midday mean soil water depletion level of high, moderate, and low irrigation treatments.

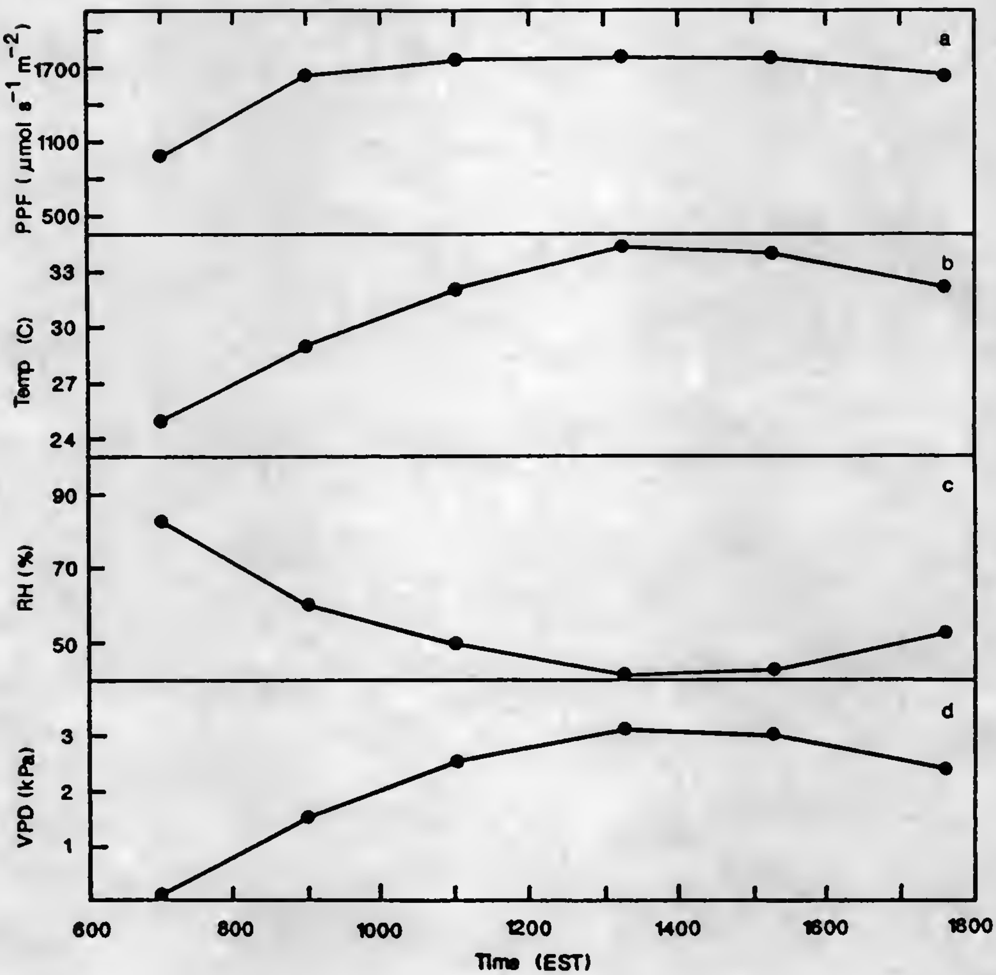

Fig. 5-7. Diurnal cycle of photosynthetic photon flux (PPF), air temperature, relative humidity (RH), and vapor pressure deficit (VPD) on 15 June 1987.

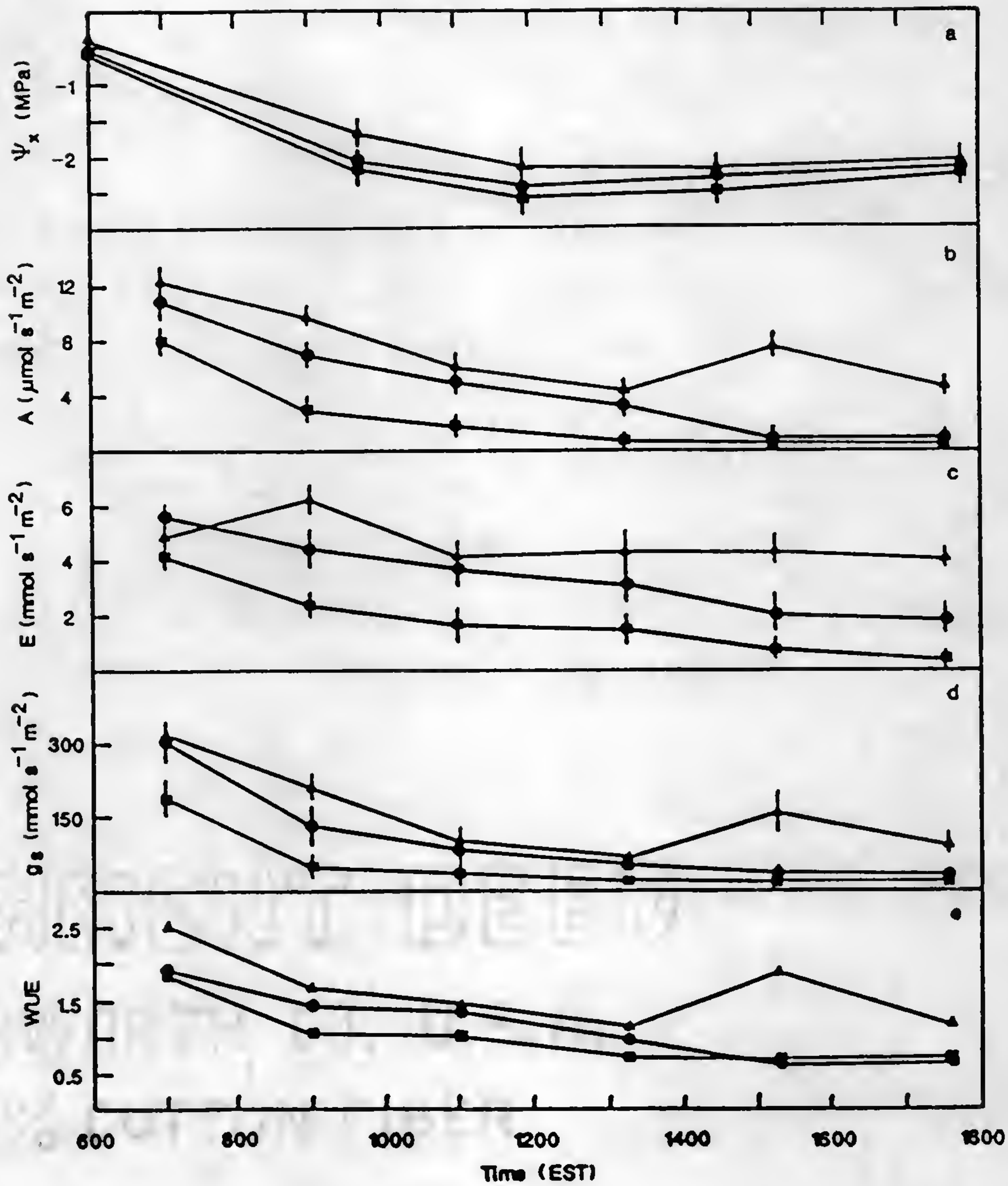

Fig. 5-8. Diurnal cycle of leaf xylem potential (Ψ_x), CO_2 assimilation (A), transpiration (E), stomatal conductance (g_s), and water use efficiency (WUE) of young 'Hamlin' orange trees on 15 June 1987 as influenced by soil water depletion (SWD). (▲) = high treatment 20% SWD, (●) = moderate treatment at 44% SWD, (■) = low treatment at 60% SWD. Bars represent SE of means, n=8.

and lemon (Kriedemann, 1968), 'Carrizo' citrange, trifoliate orange, 'Cleopatra' mandarin, 'Swingle' citrumelo, and sour orange (Syvertsen & Graham, 1985), and satsuma mandarin (Ono & Hirose, 1984). Containerized trees of several citrus species under greenhouse conditions had maximum levels comparable to this study (Khairi & Hall, 1976 a,b), as did mature orange and grapefruit trees under field conditions (Sinclair & Allen, 1982). However, these values were less than maximum CO_2 assimilation reported for mature satsuma mandarin trees under field conditions (Ono & Hirose, 1984).

The early daily peak in CO_2 assimilation, followed by a general decline thereafter for trees in the moderate and low treatments was similar to that found with containerized rough lemon trees (Thompson et al., 1965). Alternatively, the diurnal pattern of A in the high treatment closely matched that of well-watered, containerized sweet lime (Bielorai & Mendel, 1969) and mature, field-grown grapefruit on days of high VPD (Sinclair & Allen, 1982). Midday depressions of CO_2 assimilation in the mature grapefruit trees were more severe than in this study, and were considered to result from high VPD, since days characterized by more mild conditions did not show any depression. Similar midday depressions in CO_2 assimilation of rootstock seedlings were most severe on days with high VPD and temperature, but occurred only when soil water became limiting (Allen et al., 1985). In contrast, midday depressions of CO_2 assimilation occurred in potted sweet lime at a wide range of soil moisture levels and followed no consistent pattern in potted sour orange (Bielorai & Mendel, 1969). The young, field-grown 'Hamlin' orange trees in this study exhibited a gradual decline in CO_2

assimilation at all levels of soil moisture. Partial recovery in the afternoon, however, occurred only in trees in the high treatment. The greatest decrease in midday A and g_s of trees in the high treatment occurred on 15 June (Fig. 5-8), which was also the day of highest VPD (Fig. 5-7d). Moreover, midday changes in C_i paralleled those of g_s within trees in the high treatment (data not shown). As a result, reduced g_s was considered mostly responsible for midday reduction in CO_2 assimilation, which is in agreement with the previously reported mechanism of reduced CO_2 assimilation under high VPD conditions (Khairi & Hall, 1976 a,b; Kriedemann, 1968, 1971). There were no days characterized by mild conditions during the middle of June.

Containerized citrus trees and controlled conditions have been used to demonstrate decreases in CO_2 assimilation in response to decreased soil moisture content (Bielorai & Mendel, 1969; Brakke et al., 1986; Kriedemann, 1968, 1971; Ono & Hirose, 1984; Thompson et al., 1968). It is well-known that plant responses to stress under field conditions are many times dissimilar to those under controlled conditions (Begg & Turner, 1976; Davies & Lakso, 1979; Ludlow, 1976; Ludlow & Ibaraki, 1979). The only reports of citrus CO_2 assimilation under field conditions (Ono & Hirose, 1984; Sinclair & Allen, 1982) do not indicate the level of soil moisture at the time measurements were made, illustrating the need to document all factors influencing gas exchange when studying these processes.

Temperature optima for citrus photosynthesis varies from 15 to 30°C (Khairi & Hall, 1976 a,b; Kriedemann, 1968; Ono & Hirose, 1984), suggesting that high temperatures throughout much of the day

could have contributed to decreases in CO_2 assimilation. High temperature may limit A via direct effects on light reactions or carboxylation capacity (Monson et al., 1982; Stidham et al., 1982), although Khairi and Hall (1976 a,b) demonstrated the importance of reduced residual conductance at high temperatures.

Transpiration of trees in the high treatment stabilized by late morning to remain fairly constant thereafter (Fig. 5-4b, -6b, -8b). Diurnal variation of E in the moderate and low treatments was similar to A, but the decline was less precipitous after the early morning peak. Mean levels of transpiration (Table 5-2) were 80% in moderate and 50% in low treatments of those in the high treatment.

The highest instantaneous WUE (1.9-2.5) and g_s (181-316 mmol s^{-1} m^{-2}) occurred early in the morning, and the diurnal pattern of each as related to SWD was similar to CO_2 assimilation (Figs. 5-4c,d; -6c,d; -8d,e). Increased SWD caused a reduction in WUE, suggesting that A was affected to a greater degree than E. Similar results have been previously reported with sour orange and sweet lime (Bielorai & Mendel, 1969).

Variation in A closely paralleled that of g_s (Figs. 5-4, -6, -8), and regression of A on g_s showed the close relationship (e.g., $A = 0.04g_s + 0.85$, $r^2 = 0.93$, from 15 June data). A close correlation between CO_2 assimilation and stomatal conductance has traditionally been interpreted as being evidence of stomatal control over A. However, the same factors limiting stomatal conductance may have a direct effect on CO_2 fixation, and this independent effect on both processes could lead to the close correlation often found between g_s and A (Farquhar & Sharkey, 1982). Alternatively, the

close correlation between these processes could result from direct stress effects on the capacity of the photosynthetic system fo fix carbon, with stomata responding to this reduction in CO_2 assimilation (Farquhar & Sharkey, 1982; Redshaw & Meidner, 1972; Wong et al., 1979). Non-stomatal effects were responsible for the decreases in A due to SWD in this study as indicated by the increases in internal CO_2 concentration accompanying reduced g_s (Table 5-2).

Non-stomatal reduction of CO_2 assimilation may be manifested through changes in residual conductance to CO_2 in the liquid phase (Brown & Simmons, 1979; Bunce, 1977; Collatz, 1977; Mederski et al., 1975; O'Toole et al., 1976; Pearcy, 1983; Pellegrino et al., 1987; Radin & Ackerson, 1981), reduced photochemical activity (Boyer, 1976; Boyer & Bowen, 1970; Genty et al., 1987; Keck & Boyer, 1974; Nir & Poljakoff-Mayber, 1967; Sharkey & Badger, 1982; Von Caemmerer & Farquhar, 1981), or reduced carboxylation efficiency (Berkowitz & Gibbs, 1982; Boag & Portis, 1984; Huffaker et al., 1970; Jones, 1973; O'Toole et al., 1976).

Differences in environmental factors from the fall and early summer periods could explain the different diurnal pattern in gas exchange exhibited by measurements from October and June. Temperature, PPF, and VPD were lower during fall measurements than June measurements (Figs. 5-1, -3, -5, -7). Air temperature increased from <15° to 26° C on 18 October, and from 25° to 34° C during June, accompanied by soil temperatures of 23° in October and 30° C in June.

Xylem potential gradually decreased from early morning to a minimum at midday of -2.3 MPa on 15 June (Fig. 5-8a). The three SWD levels exerted less influence on xylem potential measurements than gas exchange measurements, possibly because stomatal closure prevented a further drop in xylem potential at high SWD levels. The decrease in xylem potential in the high treatment was 85% and the moderate treatment 90% of the decrease in the low treatment. Microclimatic factors controlling diurnal variation exerted much more influence on xylem potential than did SWD. This relative lack of change in xylem potential in response to large changes in soil moisture, accompanied by a closer correlation between gas exchange processes and soil moisture content, has been reported with other crops (Bates & Hall, 1981; Cock et al., 1985; Lorenzo-Minguez et al., 1985; Osonubi, 1985; Reicosky et al., 1976).

Maximum leaf to air temperature difference occurred in late morning and ranged from 1.1 to 2.1° C, depending on SWD level (data not shown). Average difference between leaf and air temperature was twice as large for trees in the low as compared to the high treatment. Increases in leaf temperature result from a reduction in evaporative cooling due to reduced transpiration (Hanson & Hitz, 1982). Leaf to air temperature difference has been used as an indicator of water stress in several crops (Clark & Hiler, 1973; Idso et al., 1981; Sojka & Karlen, 1984; Stark & Wright, 1985), including citrus (Syvertsen & Levy, 1982).

The relatively large changes in gas exchange processes with each measurement period throughout the photoperiod illustrate the need to limit gas exchange measurements to small time frames. Under

these conditions, factors independent of SWD levels would certainly confound results if measurements were made over time periods exceeding 2 hr in length.

In conclusion, SWD exerted little influence on CO_2 assimilation, transpiration, or stomatal conductance during cool days in the early fall, when these processes gradually increased before and decreased after a midday peak. However, increasing SWD resulted in decreased A, E, g_s, and instantaneous WUE of young 'Hamlin' orange trees throughout early summer days characterized by high VPD and air temperature. Reduced CO_2 assimilation of trees in the low irrigation treatment during spring and early summer may have contributed to a reduction in seasonal biomass accumulation and possibly a retardation of summer and fall growth flushes (Chapter III) when compared to trees in the high treatment.

CHAPTER VI

GROWTH OF YOUNG 'HAMLIN' ORANGE TREES USING STANDARD AND CONTROLLED-RELEASE FERTILIZERS

Introduction

Efficiency of fertilizer use can be expressed as the percent of applied nutrients recovered by the crop. Nitrogen is the most important nutrient in a citrus fertilization program and the nutrient with the most variability in efficiency of recovery. Nitrogen losses due to erosion, leaching, denitrification, and volatilization reduce N availability for plant uptake. Sandy soils and heavy rainfall in Florida are frequently associated with substantial N losses, especially through leaching. The problem is greater in areas where high water tables limit rooting depth. Concerns over energy conservation and groundwater pollution, combined with the competitive pressure to reduce production costs in the Florida citrus industry (Fairchild & Brown, 1986) make reduction of fertilizer losses desirable.

Controlled-release fertilizers potentially reduce N losses, improving efficiency of plant recovery (Khalaf & Koo, 1983; Maynard & Lorenz, 1979). Fewer applications are needed (Jackson & Davies, 1984; Koo, 1986; Maynard & Lorenz, 1979), which reduces labor and equipment costs and soil compaction by equipment.

Controlled-release fertilizers have been used on many horticultural crops (Maynard & Lorenz, 1979), including citrus. These sources increased fruit production on mature citrus (Koo, 1986) and growth of young containerized citrus (Fucik, 1974; Khalaf & Koo, 1983) when compared to more soluble fertilizer sources. In contrast, growth of young 'Orlando' tangelo trees was comparable for controlled-release sulfur-coated urea and soluble sources, but frequency of application was reduced by 50% (Jackson & Davies, 1984). Nevertheless, acceptance of controlled-release fertilizers by the Florida citrus industry has been limited (Jackson et al., 1986), primarily because of higher fertilizer costs and lack of grower experience with these materials.

Current fertilizer recommendations (Koo et al., 1984) for young citrus trees have been based on previous studies (Calvert, 1969; Rasmussen & Smith, 1961), observations, and industry trends. Recommendations call for 0.03 to 0.05 kg N/tree for newly-planted citrus, applied five to six times per year (Koo et al., 1984). Fertilizer is usually broadcast evenly in a 0.9 m diameter circle, which translates to more than 3000 kg N/year/treated ha. Young citrus trees require an adequate supply of nutrients to optimize growth; however, this rate is 10 times more than recommended levels for mature trees and may be excessive under some circumstances. Rasmussen and Smith (1961) also expressed concern that young trees were being over-fertilized and recommended reduced application frequency and rates.

Objectives of this study were to compare the effects of commonly available controlled-release and standard fertilizers on

growth of young citrus trees, and to determine the effects of three rates of application of standard fertilizer on leaf nutrient levels and tree growth.

Materials and Methods

Four field experiments were conducted at the Horticultural Unit northwest of Gainesville, Florida, using 'Hamlin' orange on sour orange rootstock. Double row beds, 16.75 m wide and 0.60-0.75 m in height, were constructed in March, 1985. Soil type was Kanapaha sand (loamy, siliceous, hyperthermic, Grossarenic, Paleaquults) underlain by a hardpan. Two tree rows 7.6 m apart were used on each bed with trees set 3.4 m apart. Irrigation was applied by 90 degree, 38 liter/hr microsprinklers located 1 m northwest of tree trunks. Available soil moisture was maintained above 20% soil water depletion in the root zone, based on results of irrigation experiments on the same site (Chapter III).

Controlled-release Fertilizers

Experiment one. Containerized and bare-rooted trees obtained from commercial nurseries were planted in May, 1985. Trunk diameter averaged 1.2 cm for bare-rooted and 0.8 cm for containerized trees. Fertilizer treatments consisted of standard fertilizer broadcast four times in the first year at 0.45 kg/tree/application and four times in the second year at 0.91 kg/tree/application (Koo et al., 1984), and isobutylidene diurea and Wonder Gro™ applied twice each year at 0.91 kg/tree/application in year 1 and 1.81 kg/tree/ application in year 2. All trees received equal amounts of fertilizer using the same formulation (8N - 2.6P - 6.6K - 2Mg - 0.2Mn - 0.12Cu - 0.2Zn - 1.78Fe). There were 12 single-tree

replications per treatment combination (three fertilizer types x two tree types) arranged as a randomized complete block, resulting in 24 trees per fertilizer type.

Trunk diameter at 5.1 cm above the bud union and canopy height and width were measured on 16 May 1985, 10 Dec. 1985, and 7 Dec. 1986. Trunk cross-sectional area was calculated from diameter and canopy volume as $(4/3)(3.14)(1/2\ H)(1/2\ W)^2$, where H=height and W=width (Westwood, 1978). This formula is used with canopies that are taller than they are wide.

Four trees per fertilizer type were carefully excavated as described in Chapter III in Dec. 1985 for measurements of fresh weight, dry weight, new root growth, and total shoot length. Roots were stained with safranin-O dye prior to planting, which allowed roots that developed in the field to be distinguished from those present at planting time.

Data were analyzed by analysis of variance. Due to lack of interactions among treatments, only data comparing fertilizer sources are discussed in this chapter. Comparison of nursery tree type is made in Chapter VII.

Experiment two. A second, similar study was begun in May, 1986 using trees from commercial nurseries different from those used in experiment one. Trunk diameters averaged 1.0 cm and 0.8 cm for bare-rooted and containerized trees, respectively. The same fertilizer sources were used and treatments were replicated six times per treatment combination (three fertilizer types X two tree types), resulting in 12 trees per fertilizer source. Trunk cross sectional areas and canopy volumes were determined on 6 May 1986, 7

Dec. 1986, and 20 Dec. 1987. Four trees per fertilizer type were excavated in December, 1986 and measurements similar to those of 1985 were made on these 8-month-old trees.

Fertilizer Rates

Experiment three. Experiments three and four were designed to determine if less than recommended fertilizer rates could be utilized to obtain adequate growth of young citrus trees. Three rates were compared on bare-rooted trees obtained from a commercial nursery (trunk diameter 1.2 cm) and planted in May, 1985. Standard fertilizer (8N - 2.6P - 6.6K - 2Mg - 0.2Mn - 0.12Cu - 0.2Zn - 1.78Fe) was applied four times throughout the year at 0.23, 0.45, or 0.68 kg/tree/application, the average recommended amount being 0.45 kg per tree (Koo et al., 1984). There were 16 single-tree replications per treatment arranged in a randomized complete block.

Canopy volumes and trunk cross sectional areas were measured on 16 May and 10 Dec. 1985. Eight trees per treatment were excavated in Dec. 1985 for plant fresh and dry weight determination. Leaf samples were collected from spring flush growth of non-fruiting shoots in August for mineral analysis. Each sample consisted of 30 leaves taken from two trees. Eight samples were collected for each fertilizer treatment. Data were analyzed by analysis of variance.

Experiment four. A study similar to experiment three was begun in March, 1987, but using container-grown trees (trunk diameter 1.3 cm) grown in plastic bags (15 cm diameter). Fertilizer was applied five times/year to 11 single-tree replications/treatment using the same three rates. Trunk cross sectional area and canopy volume were measured on 30 March and 20 Dec. 1987.

Results and Discussion

Controlled-release Fertilizers

Trees from experiment one, averaged over both classes of tree types, were initially 3.0 cm^2 in trunk cross sectional area. There were no differences in tree growth among fertilizer sources 8 and 20 months after planting (Table 6-1), when measured as trunk cross sectional area, canopy volume, fresh and dry weight, new root growth, and total shoot length. Trunk cross sectional area averaged 4.3 and 14.8 cm^2 after 8 and 20 months, respectively.

Smaller trees were obtained for experiment two with initial trunk cross sectional area averaging 2.6 cm^2. This initially smaller size was reflected in ultimate tree size after 8 and 18 months when compared to experiment one (Table 6-1). Again, no differences among fertilizer sources were found. Trunk cross sectional area averaged 3.5 and 9.5 cm^2 after 8 and 20 months, respectively. Measurements of canopy volume, fresh and dry weight, new root growth, and total shoot length followed a similar pattern to experiment one, with no differences among fertilizers.

These results indicate that isobutylidene diurea and Wonder Gro™ may be used to reduce application frequency by 50% without decreasing growth. Sulfur-coated urea has been used on young citrus trees with similar results (Jackson & Davies, 1984). The feasibility of using controlled-release fertilizers in a young tree care program should be determined on a case-by-case basis, since controlled-release materials are more expensive than more soluble fertilizers. However, reduction in application frequency and costs

Table 6-1. Effects of controlled-release fertilizers on growth of young 'Hamlin' orange trees in the field.[z]

Tree age (month)	Fertilizer source[y]	TCA[x] (cm^2)	Canopy volume (m^3)	Total fresh wt (kg)	Total dry wt (kg)	New root dry wt (kg)	Total shoot length (cm)
			Experiment one				
8	Standard	4.3	0.32	1.49	0.54	0.10	744.2
	WG	4.6	0.30	1.52	0.57	0.11	678.4
	IBDU	3.9	0.26	1.72	0.57	0.10	877.1
20	Standard	13.7	1.78				
	WG	13.7	2.32	--	--	--	--
	IBDU	16.8	1.97				
			Experiment two				
8	Standard	3.4	0.26	1.33	0.44	0.09	641.6
	WG	3.5	0.32	1.29	0.40	0.08	656.6
	IBDU	3.5	0.33	1.51	0.47	0.10	732.8
20	Standard	9.6	1.82				
	WG	8.9	1.57	--	--	--	--
	IBDU	9.9	1.90				

[z]No significant differences among treatments. Blank spaces indicate measurements were made only on 8-month-old trees.
[y]WG = Wonder Gro, IBDU = isobutylidene diurea.
[x]TCA = trunk cross sectional area.

could be realized for a limited number of replants in bearing groves.

Fertilizer Rates

Application of 0.23, 0.45, or 0.68 kg of fertilizer/tree four times throughout the season resulted in no difference in growth of the bare-rooted trees in experiment one (Table 6-2). Trunk cross sectional area increased from 1.1 to 5.4 cm^2 from May to Dec. 1985. Canopy volume, fresh weight, and dry weight averaged 0.55 m^3, 2.34 kg, and 0.90 kg, respectively. Fertilizer rate had little influence on leaf analyses, as no consistent relationship among treatments existed for all elements (Table 6-3). Levels of most elements were in the optimum or high range (Koo et al., 1984) in all cases except potassium for the lower two rates and zinc for all three rates. Leaf N was optimum for the lower two rates, and ranged between optimum and high for the 0.68 kg/tree rate.

Fertilizer rate did not significantly affect tree growth in experiment four (Table 6-2). These container-grown trees, although originally larger in trunk diameter than the bare-rooted trees of experiment three, had limited growth from March to Dec. 1987. This slow initial growth of some container-grown trees was not related to fertilizer rate and has been seen in other experiments on the same site (Chapter VII). Trunk cross sectional area increased from 1.4 to 1.7 cm^2 and final canopy volume was 0.06 m^3. These data indicate a reduction in currently recommended fertilizer rates (Koo et al., 1984) the first 2 seasons in the field may be possible in some situations without any reduction in plant growth or leaf nutrient

Table 6-2. Effects of standard fertilizer rate on growth of young 'Hamlin' orange trees in the field.[z]

Rate per tree					
Fertilizer per applic.[x] (kg)	N per yr (kg)	TCA[y] (cm^2)	Canopy volume (m^3)	Total fresh wt (kg)	Total dry wt (kg)
		Experiment three (bare-rooted)			
0.23	0.07	5.2	0.65	2.40	0.88
0.45	0.15	5.5	0.48	2.14	0.85
0.68	0.22	5.5	0.53	2.50	0.96
		Experiment four (container)			
0.23	0.09	1.7	0.06		
0.45	0.18	1.6	0.06	--	--
0.68	0.27	1.7	0.06		

[z]No significant differences among treatments.
[y]TCA = trunk cross sectional area.
[x]Fertilizer analysis was 8N - 2.6P - 6.6K - 2Mg - 0.2Mn - 0.12Cu - 0.2Zn - 1.78Fe.

Table 6-3. Influence of standard fertilizer rate on leaf analysis of young 'Hamlin' orange trees in the field.

Rate[z]	Dry wt (%)					mg/liter			
(kg/tree)	N	P	K	Ca	Mg	Fe	Zn	Mn	Cu
0.23	2.56	0.13	0.87	4.48	0.51	91.88	14.63	36.25	4.81
0.45	2.58	0.14	1.06	4.11	0.50	106.25	18.00	45.44	5.31
0.68	2.78	0.14	1.20	3.70	0.51	100.63	17.00	48.56	4.50
SE[y]	0.09	0.01	0.05	0.19	0.02	4.36	1.09	6.05	0.25

[z]Fertilizer analysis was 8N - 2.6P - 6.6K - 2Mg - 0.2Mn - 0.12Cu - 0.2Zn - 1.78Fe.

[y]SE = standard error, n = 8 samples of 15 leaves from each of two trees.

status. The low rate of 0.23 kg fertilizer/tree/application (0.07 to 0.09 kg N/year) was adequate under these circumstances.

Rasmussen and Smith (1961) suggested that 0.07 kg N/year for the first 2 years after planting was adequate for young citrus. Their study was conducted in Lake and Pasco Counties using large, bare-rooted trees with trunk diameters of over 5 cm after 1 year. In contrast, Calvert (1969) reported that trees responded more favorably to 0.22-0.33 kg N/year than 0.11 kg when grown on raised beds on marginal soil, illustrating the importance of location and soil type in determining fertilizer rates for young trees.

Many times a 1-year-old tree in the southern portion of the state may be as large as a 2-year-old tree in more northerly regions where fertilization is discontinued in September to reduce the possibility of cold damage. There is also considerable variation in size of currently-available nursery trees as well as initial growth of young citrus trees due to factors independent of fertilizer rates. These observations suggest that fertilization recommendations of non-bearing citrus may be more accurately based on tree size, as suggested by Bryan (1940), instead of being categorically based on age of trees after planting.

CHAPTER VII

GROWTH OF BARE-ROOTED AND CONTAINER-GROWN 'HAMLIN' ORANGE TREES IN THE FIELD

Introduction

Florida nurserymen have been producing bare-rooted citrus trees in field nurseries for many years. Recently, however, many citrus trees have been produced in various types of containers in greenhouses (Castle et al., 1979). Advantages of greenhouse systems include greater control over the production system, shorter growing cycles, and reduced transplant shock (Moore, 1966; Platt & Opitz, 1973; Richards et al., 1967). Much controversy exists, however, concerning growth and survival rates of container-grown compared to bare-rooted trees. Some Florida growers feel that bare-rooted trees grow faster because of their spreading, extensive root system, while others believe that containerized trees are superior due to the water-holding properties of the medium surrounding the roots. Unfortunately, many of these observations have arisen from unreplicated tests with variable soil, cultural, and environmental conditions.

Replicated comparisons of container- and field-grown grapefruit trees on sour orange rootstock in Texas have shown that size of field-grown trees is greater than container-grown trees for up to 10

years (Leyden & Timmer, 1978; Maxwell & Rouse, 1980; Maxwell & Rouse, 1984). A survey of growers in 1983-84 suggested the need for information on this subject under Florida conditions ranked second only to rootstock selection (Larry K. Jackson, Fruit Crops Dept., Univ. of Fla., personal communication).

The objective of this study was to compare establishment and initial canopy and root growth of container-grown and bare-rooted citrus trees under the same cultural, climatic, and edaphic conditions. In addition, the effect of removal of container medium on growth of containerized trees was studied.

Materials and Methods

Four field experiments were conducted at the Horticultural Unit located northwest of Gainesville using 'Hamlin' orange trees on sour orange rootstock. Beds (16.75 m width x 0.60-0.75 m height x 85 m length) were constructed in March, 1985. Soil type was Kanapaha sand (loamy, siliceous, hyperthermic, Grossarenic, Paleaquults) underlain by an impervious hardpan. Two tree rows 7.6 m apart were used on each bed with trees set 3.4 m apart. Irrigation water was applied by 90 degree, 38 liter/hr microsprinklers located 1 m northwest of tree trunks. Available soil moisture was maintained above 20% soil water depletion in the root zone, based on results of irrigation experiments on the same site (Chapter III).

Experiment one. Greenhouse-grown trees in 10.2 x 10.2 x 35.6 cm plastic containers (Citripots™) and field-grown, bare-rooted trees were obtained from commercial nurseries in May, 1985 and planted as part of a study comparing tree types and fertilizer sources (Chapter VI). Typical nursery trees were obtained, with

bare-rooted trees being larger than containerized trees. Trunk diameter ca. 5 cm above the bud union averaged 1.2 and 0.8 cm for bare-rooted and containerized trees, respectively. Twelve single tree replications per treatment combination (three fertilizer types X two tree types) were used, resulting in 36 trees per tree type.

A mark was painted on each tree ca. 5 cm above the bud union. Trunk diameter at this mark and canopy height and width were measured on 16 May 1985, 10 Dec. 1985, and 7 Dec. 1986. Trunk cross-sectional area was calculated from diameter and canopy volume was calculated as $(4/3)(3.14)(1/2H)(1/2W)^2$, where H = height and W = width (Westwood, 1978). This formula is used when a canopy is taller than it is wide.

Six trees for each tree type were carefully excavated as described in Chapter III in Dec. 1985 for growth measurements and root examination. Total plant fresh and dry weight, new root growth, and total shoot length were measured after 8 months in the field. Roots of bare-rooted trees were stained with safranin-O dye prior to planting, which allowed roots that developed in the field to be distinguished from those present at planting time. Roots extending out of the media in containerized trees were considered to have developed in the field.

Weight and shoot length measurements were subjected to analysis of variance and canopy volume and trunk cross sectional area to analysis of covariance to standardize differences in initial plant measurements. Due to lack of interactions among treatments, only data comparing nursery tree type are discussed in this chapter. Comparisons of fertilizer sources are made in Chapter VI.

<u>Experiment two</u>. A similar study was begun in May, 1986 using trees from commercial nurseries different from those used in experiment one. Trees of more uniform size than those used in experiment one were selected, with trunk diameter averaging 1.0 and 0.8 cm for bare-rooted and containerized, respectively. The same fertilizer sources were compared (Chapter VI) and six single tree replications were used per treatment combination (three fertilizer sources X two tree types), resulting in 18 trees per tree type. Trunk cross sectional area and canopy volume were determined on 6 May 1986, 7 Dec. 1986, and 20 Dec. 1987. Six trees per tree type were excavated in December, 1986 and measurements similar to those of 1985 were made on these 8-month-old trees. Analysis of data was as described in experiment one.

<u>Experiment three</u>. Poor root growth was observed on some containerized trees in experiment one, therefore a third experiment was designed to compare the effect of removing different amounts of container media on subsequent growth. Greenhouse-grown trees produced in 10.2 cm citripots and averaging 0.8 cm in trunk diameter were treated by using water from a garden hose to rinse away all, the bottom half, or no media (control) prior to planting in May, 1986. Treatments were replicated nine times in a randomized complete block. Standard fertilizer was applied using recommended rates (Koo et al., 1984) and irrigation was as described previously. Trunk cross sectional areas and canopy volumes were measured on 6 May and 7 Dec. 1986. All tree root systems were excavated in Dec. 1986 for root examination and growth measurements. Plant fresh and dry weight, and dry weight of new roots were measured after

excavation. Data on weights were subjected to analysis of variance and data on trunk cross sectional area and canopy volume to analysis of covariance.

Experiment four. A study combining aspects of all three preceding experiments was begun in April 1987 using a new bed constructed in January 1987. Greenhouse-grown trees in 15.2 cm plastic bags and averaging 1.35 cm in trunk diameter were treated prior to planting by rinsing away all of the media, by breaking up the root ball by hand, or with no pre-plant treatment. These container-grown trees, planted by the three methods, were compared to bare-rooted trees averaging 1.34 cm in trunk diameter. Treatments were replicated 12 times in a randomized complete block. Irrigation and fertilizer rates were as described previously. Trunk cross sectional area and canopy volume were determined on 14 April and 5 Dec. 1987. All tree root systems were excavated in Dec. and plant fresh and dry weight, dry weight of new roots, and total shoot length were measured after excavation. Data were analyzed as in experiment three. Where treatments were significantly different, Dunnett's t test (Dunnett, 1964) was used to compare each container planting method against the bare-rooted treatment.

Results and Discussion

Tree size, expressed as trunk cross sectional area, canopy volume, plant fresh and dry weights, total shoot length, and dry weight of new roots, were significantly less for container-grown than bare-rooted trees after 8 months of growth in experiment one (Fig. 7-1, Table 7-1). Canopy volume was affected most, as container-grown trees were 25% the size of bare-rooted trees (Fig.

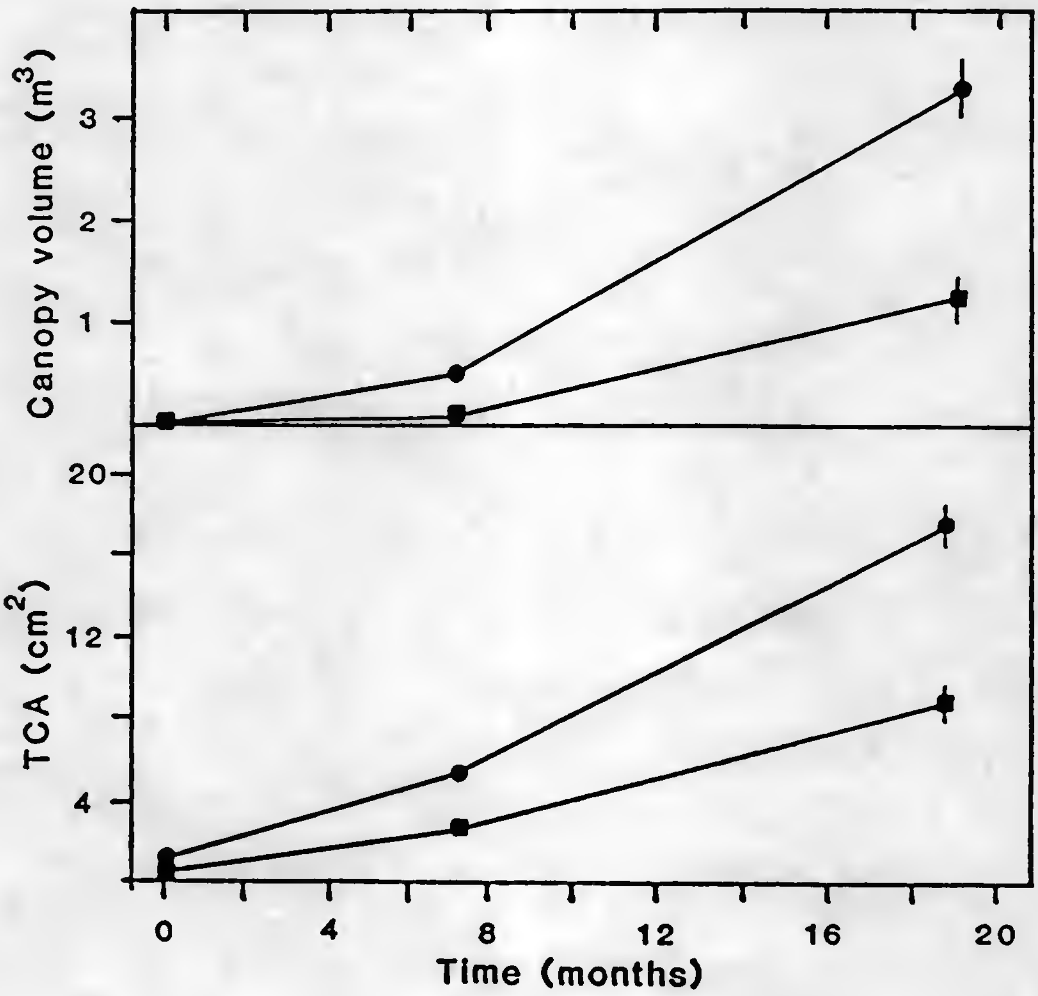

Fig. 7-1. Effect of 'Hamlin' orange nursery tree type on increase in trunk cross sectional area (TCA) and canopy volume from May 1985 to Dec. 1986. Bars represent standard errors of means, n=36. (●) = bare-rooted, (■) = container-grown.

Table 7-1. Effect of nursery tree type on growth of 'Hamlin' orange trees after 8 months in the field.

Tree type	Fresh wt (kg)	Dry wt (kg)	Dry wt new roots (kg)	Total shoot length (cm)
	Experiment one (May-Dec. 1985)			
Bare-rooted	2.18	0.76	0.15	1056.4
Container	0.86	0.31	0.05	439.9
	**	**	**	**
	Experiment two (May-Dec. 1986)			
Bare-rooted	1.55	0.49	0.11	792.0
Container	1.17	0.36	0.06	613.9
	*	*	**	ns

ns,*,** Nonsignificant or significant at the 5% and 1% levels, respectively, by F test. Mean of six trees/treatment.

7-1). Size of bare-rooted trees, measured as trunk cross sectional area and canopy volume, remained significantly greater than that of container-grown trees 20 months after planting (Fig. 7-1). Trunk cross sectional area of container-grown trees averaged 51% and canopy volume 37% the size of bare-rooted trees.

Bare-rooted trees in experiment two were also significantly larger than container-grown trees after 8 months in the field, as determined by trunk cross sectional area, canopy volume, plant fresh and dry weight, and dry weight of new roots (Fig. 7-2, Table 7-1). Total shoot length of the tree types was not significantly different, however. Averaged over all measurements, container-grown trees were 68% as large as bare-rooted trees. After 20 months in the field, container-grown trees averaged 84% the size of bare-rooted trees based on trunk cross sectional area and canopy volume.

Leyden and Timmer (1978) concluded that container-grown citrus trees would be smaller and less productive initially than field-grown trees based on a 2.5 year comparison of grapefruit/sour orange trees. Maxwell and Rouse (1980, 1984), however, compared grapefruit/sour orange trees through 10 years in the field, and reported field-grown nursery trees were larger than container-grown trees, but that yield did not differ. These studies are not comparable to Florida conditions because container stock was not grown under greenhouse conditions, container size (up to 5.8 liter) was larger than used in Florida, and field-grown trees were transplanted ball and burlapped.

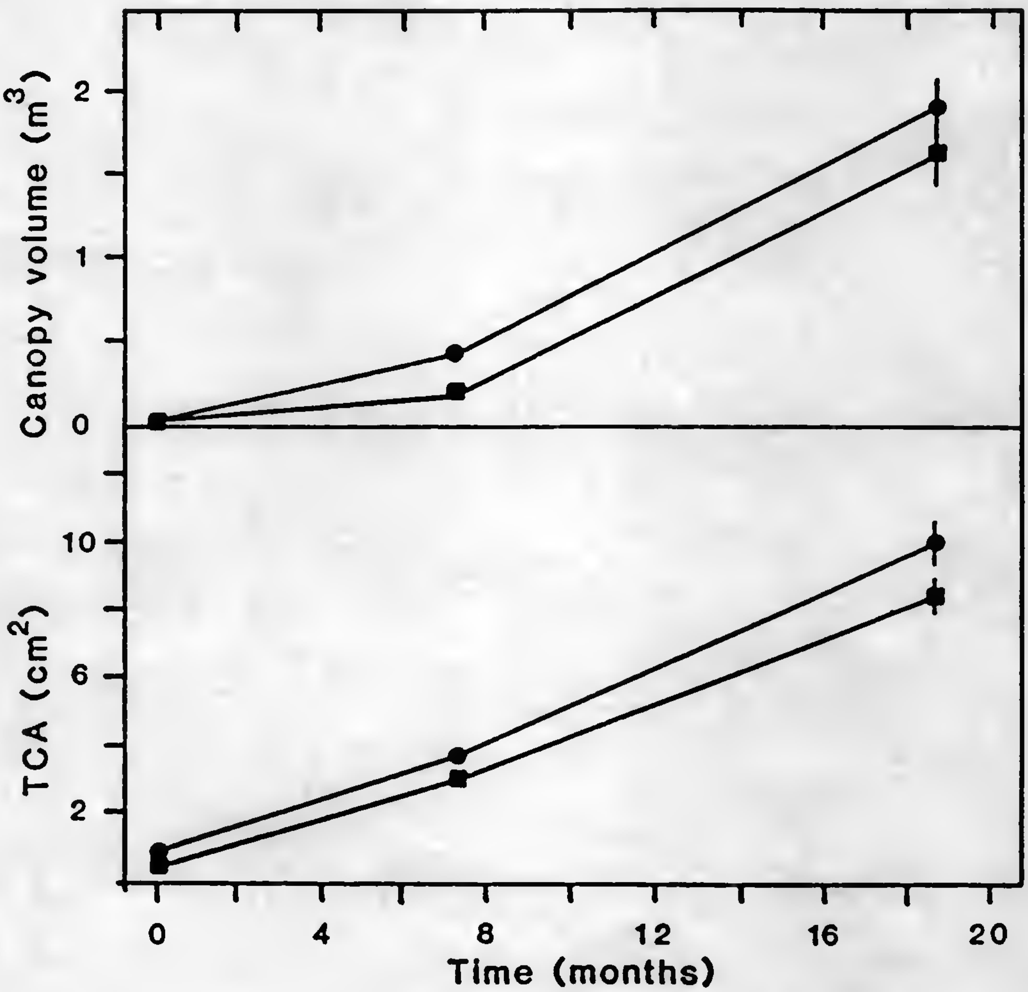

Fig. 7-2. Effect of 'Hamlin' orange nursery tree type on increase in trunk cross sectional area (TCA) and canopy volume from May 1986 to Dec. 1987. Bars represent standard errors of means, n=18. (●) = bare-rooted, (■) = container-grown.

Webber (1932) found that after roguing off-type rootstocks, initial 'Washington' navel orange tree size was not correlated with tree size after 8 years. Similarly, Gardner and Horanic (1959) found no relationship between initial and ultimate tree size with 17-year-old 'Parson Brown' and 'Valencia' orange trees. Unfortunately, neither of these reports discussed the influence of initial tree size on precosity and size during the early years of bearing. The data presented here indicate that nursery tree size strongly influences growth of citrus trees during the first 20 months in the field.

Initial size difference may not have been the only factor determining the large difference in growth of bare-rooted and container-grown trees in experiment one. Roots of many container-grown trees after 8 months in the field were limited to a small volume of soil surrounding the media. Container-grown trees in experiment two, however, did not respond similarly, as all excavated trees had root growth greater than two feet beyond the container media. This is not reflected in root dry weight (Table 7-1), which indicates that initial root extension into field soil may be as important as total root growth measured as biomass accumulation. These observations also indicate that initial root growth from newly-planted containerized trees is highly variable from year-to-year or nursery-to-nursery.

Removal of potting medium prior to planting container-grown trees in experiment three significantly improved tree growth, measured as plant fresh and dry weight, new root dry weight, canopy volume, and trunk cross sectional area (Table 7-2). Differences

Table 7-2. Effect of removing medium prior to planting on growth of containerized 'Hamlin' orange trees from May to Dec., 1986.

Amount of container medium removed	Fresh wt (kg)	Dry wt (kg)	Dry wt new roots (kg)	Canopy volume (m^3)	TCA[z] (cm^2)
All	1.46	0.47	0.12	0.38	3.10
1/2	1.40	0.45	0.09	0.24	3.16
Control	1.17	0.36	0.06	0.17	2.77
SE[y]	0.13	0.04	0.01	0.06	0.19

[z]Trunk cross sectional area.
[y]SE = standard error, n = 9.

between the control and treatment with all medium removed were two-fold or greater for root growth and canopy volume.

Growth of bare-rooted trees in experiment four was significantly greater than container-grown trees in all three planting methods, measured as plant fresh and dry weight, new root dry weight, total shoot length, canopy volume, and trunk cross sectional area (Table 7-3). Size of bare-rooted trees was more than three times greater than the mean size of all container-grown trees, averaged over all measurements. Statistical comparison of the container planting methods was not made, however, from the means in Table 7-3, it is evident that medium removal prior to planting did not increase tree growth that year. Limited lateral root growth of container-grown trees occurred as in the trees planted in 1985 (experiment one).

Studies from California suggest that water movement from field soil to organic media around the roots may be slow (Richards et al., 1967). This is particularly true as the medium dries and its hydraulic conductivity decreases. One advantage of a California mix was that it was easily shaken loose prior to planting (Platt & Opitz, 1973). Drying of container medium after planting due to evapotranspiration, drainage (Nelms & Spomer, 1983; Warneke et al., 1975), and difficulty in rewetting could lead to increased plant stress and decreased growth. Death of containerized landscape plants has been attributed to these phenomena (Costello & Paul, 1975). Survival of container-grown and bare-rooted citrus trees was similar in our study, but slow initial growth occurred for

Table 7-3. Growth of bare-rooted and container-grown 'Hamlin' orange trees as influenced by planting procedure (April-Dec., 1987).

Treatment[z]	Fresh wt (kg)	Dry wt (kg)	Dry wt new roots (kg)	Total shoot length (cm)	Canopy volume (m^3)	TCA[y] (cm2)
BR	1.35	0.45	0.09	844.3	0.42	3.45
C-1	0.51**	0.21**	0.03**	446.6**	0.07**	1.74**
C-2	0.33**	0.15**	0.02**	314.3**	0.04**	1.53**
C-3	0.58**	0.23**	0.03**	498.4**	0.10**	1.99**

[z]BR = bare-rooted; C-1 = container-grown, all media removed; C-2 = container-grown, root ball broken up; C-3 = untreated container-grown.
[y]Trunk cross sectional area.
**Different from BR according to Dunnett's t test, 1% level.
Mean of 11 trees/treatment.

containerized trees and has been observed in other plantings on the same site.

Poor root growth accompanied and may have contributed to slow initial growth of many container-grown trees. Kaufmann (1968) reported that pine root tips matured in dry soils, resulting in reduced elongation. Severe drying of container medium following planting could cause the same results. Root growth of pine seedlings grown in a medium high in peat and planted in sandy loam to clay loam was much less than when grown in soil that closely resembled that in which they were planted (Hellum, 1981). These factors may have contributed to reduced root growth in our study, except in the case of experiment four, where medium removal did not enhance root growth. Other factors associated with post-plant root growth of forestry species that are produced in containers are season of planting (Lavender & Cleary, 1974; Tinus, 1974), container characteristics (Elam et al., 1981; Hiatt & Tinus, 1974; Hite, 1974; Tinus & Owston, 1984; Van Eerden & Arnott, 1974), and acclimation to field conditions prior to transplanting (Rook, 1973; Timmis, 1974; Tinus & Owston, 1984). Furthermore, less post-plant root growth occurrs as the length of time seedlings are maintained in containers is lengthened (Hellum, 1981). Elam et al. (1981) reported a large variation in the effects of container and media characteristics on growth of oak species.

Lack of acclimation to field growing conditions prior to planting may play a role in the poor initial growth seen in some containerized greenhouse-grown citrus trees. Optimum conditions for growth in the greenhouse, combined with little concern for

acclimation to field conditions, resulted in poor survival rates for containerized forestry seedlings (Tinus & Owston, 1984). Potted plants transferred from a shaded, humid environment to full sun typically suffer stress even with optimum soil moisture conditions in the field (Kramer & Kozlowski, 1979). Moreover, vigor of container-grown ornamental plants frequently declines rapidly following removal from a high liquid N fertilization program (T.H. Yeager, Ornamental Hort. Dept., Univ. of Fla., personal communication). The problem is lessened by lowering N rates near the end of the production cycle or by utilizing controlled-release fertilizers instead of a liquid fertilizer program. Acclimation is also promoted by reduced irrigation frequency in the nursery (Rook, 1973).

Season of planting may affect the degree of acclimation needed prior to transplanting greenhouse-grown citrus trees. The dry windy conditions that frequently occur in Florida during early spring months may be much harsher conditions for the greenhouse-grown transplants than would occur at other times. Windy days with relative humidity below 30% occurred in 1987 (experiment four) shortly after transporting the greenhouse-grown trees to the field.

Many container-grown citrus trees are being produced and planted throughout Florida with a high degree of success. However, most of these trees are initially smaller than bare-rooted trees and have distinctively different rooting and branching patterns. Inconsistencies in the results of this series of field trials and in performance of container-grown citrus trees in the commercial industry indicate that the question of how well container-grown

trees perform in the field cannot be answered categorically. Initial growth of containerized trees depends largely on the morphological and physiological condition of the stock, condition of the site, planting operation, care after planting, weather at time of and shortly after planting, container and medium characteristics, length of time in the nursery, and rootstock/scion choices. It is imperative that nurserymen, planting crews, and grove managers work closely together to ensure widespread successful establishment and growth of containerized, greenhouse-grown citrus trees.

In conclusion, our data suggest that bare-rooted trees will grow faster than container-grown trees for the first 2 seasons if compared under the same cultural, edaphic, and environmental conditions. Survival is excellent for both types of nursery trees if proper care is given after planting. It is important to choose healthy, unstressed, uninjured trees initially, whether bare-rooted or containerized, to improve growth after planting.

CHAPTER VIII

CONCLUSIONS

Young citrus tree care is an important and costly effort in the Florida citrus industry. Understanding the influence of nursery conditions and field management decisions on young tree growth and development is vital to maximize growth and survival.

The first portion of this research demonstrated the influence of irrigation and soil water deficits on growth of young 'Hamlin' orange trees. Canopy growth was similar with high (20% soil water depletion [SWD]) and moderate (45% SWD) irrigation treatments in 2 out of 3 years, but was reduced with the low treatment (65% SWD). Summer and fall flushes were also delayed sometimes by the moderate and low treatments. The low treatment did not decrease individual shoot and leaf growth rates or ultimate size, but sometimes decreased shoot number. Trees in the high treatment received an average of 31; in the moderate treatment, an average of 11; and in the low treatment an average of two irrigations annually. Trees in the moderate treatment received approximately 50% less water than those in the high treatment. Irrigation frequency during dry periods was 2-3 days for the high and 4-6 days for the moderate treatments.

Total root growth in relation to treatments followed patterns similar to shoot growth. More than 90% of the roots (dry weight basis) were covered by the 90° microsprinkler emitters after one season of growth. This observation, combined with the lack of growth difference in second season trees irrigated with 90° and 180° emitters, suggests that 90° emitters have sufficient coverage to be used more than one season. Most root growth occurred between 10 and 30 cm in depth. Irrigation times with young citrus trees should be limited to replenish soil moisture only in these shallow zones.

Soil water deficit influenced xylem potential relatively little compared to gas exchange processes during early summer days characterized by high vapor pressure deficit and temperature. Increasing soil water deficit decreased CO_2 assimilation (A), transpiration (E), stomatal conductance (g_s), and instantaneous water use efficiency of the young citrus trees. While A and g_s were highly correlated, stomatal limitation of A was assumed to be of little importance in soil water deficit influence on A, based on internal CO_2 concentrations. Midday depressions of A, however, were assumed to result from stomatal closure, as internal CO_2 concentration decreased with g_s and A during these midday measurements. Soil water deficits had little influence on A, E, or g_s during the fall when temperatures were cooler.

The precise level of SWD at which microsprinkler irrigation should be scheduled cannot be determined from these experiments, but is most likely between 20 and 45%, depending on tree age, soil type, and location in Florida.

The second portion of this research demonstrated that currently used fertilization rates may be excessive and that controlled-release fertilizers may be a viable alternative to standard methods. Applying granular 8% N fertilizer four to five times per season at rates of 0.23, 0.45 (average recommended rate), and 0.68 kg/tree resulted in similar growth of young 'Hamlin' orange trees for the first year, suggesting that commonly used rates may be substantially reduced in many situations. Wonder Gro™ and isobutylidene diurea applied half as many times as standard granular fertilizer at the same annual rate also resulted in similar tree growth to the standard treatment. Controlled-release sources may be beneficial in certain situations, especially with a limited number of scattered resets where application costs are high. Large variations in tree size due to nursery tree type, location within the state, and other factors not associated with fertilization rate suggest that recommendations for non-bearing trees may be more accurately based on tree size instead of categorically based on the number of years in the field.

The third part of this project demonstrated a substantial influence of nursery tree type on initial growth of young 'Hamlin' orange trees in the field. Bare-rooted, field-grown trees grew faster than containerized, greenhouse-grown trees for at least 2 seasons when compared under the same cultural, edaphic, and environmental conditions. Removal of potting medium prior to planting container-grown trees improved tree growth in one year, but had no effect in another. Considerable variability occurred in growth rates of container-grown trees, and further research is

needed to identify potential factors controlling the initial performance of these trees in the field. Conditions of the nursery operation and the field at time of planting, as well as certain morphological and physiological factors of the tree that may influence initial growth need to be identified and correlated with post-plant growth.

These studies suggest that microsprinkler irrigation may be optimized by using 90° emitters to maintain soil water content above 20-45% SWD (3-6 day frequency under these conditions) and limiting irrigation times to 1-2 hr. To increase efficiency of young citrus fertilization programs, these experiments suggest that emphasis should be placed mainly on rate reduction and in some cases the use of controlled-release sources. Nursery stock condition may affect initial growth after field-planting citrus trees, and care should be taken to choose healthy, unstressed, and uninjured trees.

APPENDIX A

MEAN MONTHLY PAN EVAPORATION AND MAXIMUM AND MINIMUM AIR TEMPERATURES FOR MAY-DEC. 1985, MAY-DEC. 1986, AND APRIL-DEC. 1987. DATA WERE OBTAINED FROM THE IFAS AGRONOMY FARM WEATHER STATION LOCATED ABOUT 14 KM FROM THE HORTICULTURAL UNIT.

	Month								
	A	M	J	J	A	S	O	N	D
					1985				
Pan E (mm day^{-1})		6.9	5.7	4.5	4.2	4.4	4.1	2.9	2.3
Max temp (°C)		33.5	33.6	32.8	32.0	30.9	30.2	26.9	22.7
Min temp (°C)		17.7	21.9	21.4	22.1	20.6	19.6	16.2	9.4
					1986				
Pan E (mm day^{-1})		7.2	5.4	6.2	4.7	4.8	3.4	2.3	2.7
Max temp (°C)		30.4	33.3	34.1	32.6	32.7	29.1	26.9	22.7
Min temp (°C)		15.8	21.0	21.7	21.5	20.9	17.1	17.1	13.0
					1987				
Pan E (mm day^{-1})	6.2	5.8	5.6	4.9	5.4	4.2	3.1	4.5	2.4
Max temp (°C)	29.1	30.1	33.0	33.8	33.9	32.1	26.5	24.4	21.5
Min temp (°C)	12.5	18.0	21.1	22.3	22.6	20.8	13.1	12.4	7.5

APPENDIX B

WHOLE PLANT FRESH AND DRY WEIGHTS AND SHOOT:ROOT RATIO OF YOUNG 'HAMLIN' ORANGE TREES AS RELATED TO IRRIGATION BASED ON SOIL WATER DEPLETION.

Soil water depletion (%)	Whole plant fresh weight (g)	Whole plant dry weight (g)	Shoot: root ratio
	1985 (n=20)		
20 (High)	2176.4	773.3	1.16
45 (Mod.)	1991.0	759.7	1.28
65 (Low)	1645.6**	633.9**	1.21
	1986 (n=21)		
20 (High)	2197.0	721.3	1.18
45 (Mod.)	2195.8	721.1	1.16
65 (Low)	1786.0	562.1	1.12
	1987 (n=5)		
20 (High)	1857.2	651.0	1.54
45 (Mod.)	1183.4*	428.4*	1.54
65 (Low)	1050.0*	389.2*	1.49

*,**Response is significant when compared with the 20% soil water depletion treatment by the Williams' method, 5% and 1%, respectively.

APPENDIX C

REGRESSION EQUATIONS AND COEFFICIENTS OF DETERMINATION (r^2) REPRESENTING THE CUMULATIVE PERCENTAGE OF TREES IN THREE IRRIGATION TREATMENTS GROWING OVER THE SEASON.

Flush	Equation	r^2
	1985	
one	$Y_{20\%} = -31.36 + 9.57day - 0.1678day^2$	0.92
	$Y_{45\%} = -28.07 + 9.37day - 0.1662day^2$	0.89
	$Y_{65\%} = -27.33 + 10.58day - 0.2019day^2$	0.80
two	$Y_{20\%} = -447.70 + 13.63day - 0.0840day^2$	0.97
	$Y_{45\%} = -316.05 + 8.78day - 0.0458day^2$	0.95
	$Y_{65\%} = -197.06 + 6.03day - 0.0314day^2$	0.84
three	$Y_{20\%} = -521.10 + 7.31day - 0.0214day^2$	0.82
	$Y_{45\%} = -221.00 + 2.85day - 0.0062day^2$	0.89
	$Y_{65\%} = -98.30 + 1.17day - 0.0018day^2$	0.85
	1986	
one	$Y_{20\%} = -17.4 + 10.52day - 0.2265day^2$	0.99
	$Y_{45\%} = -9.21 + 7.11day - 0.1141day^2$	0.99
	$Y_{65\%} = -26.93 + 9.01day - 0.1610day^2$	0.99
two	$Y_{20\%} = -231.33 + 7.56day - 0.0415day^2$	0.86
	$Y_{45\%} = -153.77 + 4.48day - 0.0200day^2$	0.98
	$Y_{65\%} = -96.28 + 2.47day - 0.0068day^2$	0.97
three	$Y_{20\%} = -560.18 + 8.04day - 0.0240day^2$	0.95
	$Y_{45\%} = -360.99 + 5.06day - 0.0145day^2$	0.97
	$Y_{65\%} = -217.06 + 2.86day - 0.0072day^2$	0.99
	1987	
one	$Y_{20\%} = -39.43 + 4.27day$	0.94
	$Y_{45\%} = -39.14 + 4.19day$	0.93
	$Y_{65\%} = -33.7 + 3.71day$	0.78
two	$Y_{20\%} = -1054.05 + 22.57day - 0.1085day^2$	0.93
	$Y_{45\%} = -758.64 + 15.55day - 0.700day^2$	0.95
	$Y_{65\%} = -509.48 + 9.88day - 0.0401day^2$	0.92
three	$Y_{20\%} = -767.17 + 9.85day - 0.0275day^2$	0.82
	$Y_{45\%} = -816.57 + 9.73day - 0.0256day^2$	0.97
	$Y_{65\%} = -618.5 + 7.08day - 0.0174day^2$	0.96

APPENDIX D

MEAN AND MAXIMUM LEAF TO AMBIENT AIR TEMPERATURE DIFFERENCE OF 'HAMLIN' ORANGE TREES IN JUNE 1987 AS INFLUENCED BY SOIL WATER DEPLETION.

Soil water depletion (%)	Leaf to air temp. diff. (°C) maximum	minimum
	12 June 1987	
19[z]	1.3	0.8
28	1.5	0.9
53	2.1	1.4
	13 June 1987	
2	1.1	0.6
32	1.3	0.8
55	2.0	1.3
	15 June 1987	
20	1.2	0.7
45	1.4	0.8
60	2.0	1.4

[z]Midday mean soil water depletion level of high, moderate, and low irrigation treatments.

LITERATURE CITED

Acevedo, E., T.C. Hsiao, and D.W. Henderson. 1971. Immediate and subsequent growth responses of maize leaves to changes in water status. Plant Physiol. 48:631-636.

Aiyappa, K.M. and K.C. Srivastava. 1965. Studies on root system of Coorg Mandarin seedling trees. Indian J. Hort. 22:122-130.

Alijbury, F.K., A.W. Marsh, and J. Huntmer. 1974. Water use with drip irrigation. p. 341-345. Proc. Second Int. Drip Irrigation Congress.

Allen, L.H., M.P. Brakke, and J.W. Jones. 1985. Climate, soil water, and CO_2 effects on citrus seedling photosynthesis and transpiration. Agronomy Abstr. 77:10.

Allen, S.E. and D.A. Mays. 1974. Coated and other slow-release fertilizers for forages. p. 559-582. In: D.A. Mays (ed.). Forage fertilization. Amer. Soc. Agron., Madison, Wisc.

Aribi, K.B. 1985. Water use and growth of young citrus trees as a function of irrigation management and ground cover conditions. M.S. Thesis. Univ. of Fla., Gainesville.

Atkinson, D. 1980. The distribution and effectiveness of the roots of tree crops. p. 424-490. In: J. Janick (ed.). Horticultural Reviews, Vol. 2 AVI, Westport, Conn.

Barker, A.V. and H.A. Mills. 1980. Ammonium and nitrate nutrition of horticultural crops. p. 395-423. In: J. Janick (ed.). Horticultural Reviews, Vol 2 AVI, Westport, Conn.

Barnette, R.M. 1936. Major plant food elements. Proc. Fla. State Hort. Soc. 49:4-9.

Bates, L.M. and A.E. Hall. 1981. Stomatal closure with soil water depletion not associated with changes in bulk leaf water status. Oecologia 50:62-65.

Bates, L.M. and A.E. Hall. 1982. Diurnal and seasonal responses of stomatal conductance for cowpea plants subjected to different levels of environmental drought. Oecologia 54:304-308.

Begg, J.E. and N.C. Turner. 1976. Crop water deficits. Adv. Agron. 28:161-217.

Bennett, J.M., T.R. Sinclair, R.C. Muchow, and S.R. Costello. 1987. Dependence of stomatal conductance on leaf water potential, turgor potential, and relative water content in field-grown soybean and maize. Crop Sci. 27:984- 990.

Berkowitz, G.A. and M. Gibbs. 1982. Effect of osmotic stress on photosynthesis studied with the isolated spinach chloroplast. Plant Physiol. 70:1143-1148.

Bester, D.H., D.C. Lotter, and G.H. Veldman. 1974. Drip irrigation on citrus. p. 58-64. Proc. Second Int. Drip Irrigation Congress. San Diego, CA.

Beukes, D.J. 1984. Apple root distribution as effected by irrigation at different soil water levels on two soil types. J. Amer. Soc. Hort. Sci. 109:723-728.

Bevington, K.B. 1983. Growth and development of citrus roots in relation to season, rootstock, shoot growth, and environmental factors. Ph.D. Diss., Univ. of Fla., Gainesville.

Bevington, K.B. and W.S. Castle. 1982. Development of the root system of young 'Valencia' orange trees on rough lemon and Carrizo citrange rootstocks. Proc. Fla. State Hort. Soc. 95:33-37.

Bevington, K.B. and W.S. Castle. 1985. Annual root gorwth pattern of young citrus trees in relation to shoot gorwth, soil temperature, and soil water content. J. Amer. Soc. Hort. Sci. 110:840-845.

Bielorai, H. 1977. The effect of drip and sprinkler irrigation on grapefruit yield. Proc. Int. Soc. Citric. 1:99-103.

Bielorai, H. 1978. The prospects of water management for optimum citrus growth and production. p. 227-233. Proc. Int. Soc. Citric.

Bielorai, H. 1982. The effect of partial wetting of the root zone on yield and water use efficiency in a drip- and sprinkler-irrigated mature grapefruit grove. Irrig. Sci. 3:89-100.

Bielorai, H., S. Dasberg, Y. Erner, and M. Brum. 1981. The effect of various soil moisture regimes and fertilizer levels on citrus yield response under partial wetting of the root zone. Proc. Int. Soc. Citric. 2:585-589.

Bielorai, H., S. Dasberg, Y. Erner, and M. Brum. 1984. The effect of fertigation and partial wetting of the root zone on production of Shamouti oranges. Proc. Int. Soc. Citric. 1:118-121.

Bielorai, H. and K. Mendel. 1969. The simultaneous measurement of apparent photosynthesis and transpiration of citrus seedlings at different soil moisture levels. J. Amer. Soc. Hort. Sci. 94:201-204.

Bingham, F.T., S. Davis, and E. Shade. 1971. Water relations, salt balance, and nitrate leaching losses of a 960-acre citrus watershed. Soil Sci. 112:410-418.

Black, C.R., D.Y. Tang, C.K. Ong, A. Solon, and L.P. Simmonds. 1985. Effects of soil moisture stress on the water relations and water use of groundnut stands. New Phytol. 100:313-328.

Blackman, P.G. and W.J. Davies. 1985a. Cytokinins, abscisic acid and the control of plant water balance. Acta Hort. 171:255-261.

Blackman, P.G. and W.J. Davies. 1985b. Root to shoot communication in maize plants of the effects of soil drying. J. Exp. Bot. 36:39-48.

Boag, S. and A.R. Portis, Jr. 1984. Inhibited light activation of fructose and sedoheptulose bisphosphatase in spinach chloroplasts exposed to osmotic stress. Planta 160:33-40.

Bohm, W. 1976. In situ estimation of root length at natural soil profiles. J. Agric. Sci., Camb. 87:365-368.

Boyer, J.S. 1976. Water deficits and photosynthesis. p. 153-190. In: T.T.Kozlowski (ed.). Water deficits and plant growth. Vol IV. Academic Press, NY.

Boyer, J.S. and B.L. Bowen. 1970. Inhibition of oxygen evolution in chloroplasts isolated from leaves with low water potentials. Plant Physiol. 45:612-615.

Brakke, M.P., L.H. Allen, and J.W. Jones. 1986. Effect of partial root-volume irrigation on photosynthesis and transpiration of citrus treelings. Agronomy Abstr. 78:12.

Briggs, G.M., T.W. Jurik, and D.M. Gates. 1986. Non-stomatal limitation of CO_2 assimilation in three tree species during natural drought conditions. Physiol. Plant. 66:521-526.

Brouwer, R. 1962. Nutritive influences on the distribution of dry matter in the plant. Neth. J. Agric. Sci. 10:399-408.

Brown, R.H. and R.E. Simmons. 1979. Photosynthesis of grass species differing in CO_2 fixation pathways. I. Water use efficiency. Crop Sci. 19:375-379.

Bryan, O.C. 1940. Malnutrition symptoms of citrus with practical methods of treatment. State of Florida Bull. No. 93.

Bunce, J.A. 1977. Leaf elongation in relation to leaf water potential in soybean. J. Exp. Bot. 28:156-161.

Cahoon, G.A., M.R. Huberty, and M.J. Garber. 1961. Irrigation frequency effects on citrus root distribution and density. Proc. Amer. Soc. Hort. Sci. 77:167-172.

Cahoon, G.A., L.H. Stolzy, M.J. Garber, and E.S. Morton. 1964. Influence of nitrogen and water on the root density of mature 'Washington' navel orange trees. Proc. Amer. Soc. Hort. Sci. 85:224-231.

Calvert, D.V. 1969. Effects of rate and frequency of fertilizer applications on growth, yield and quality factors of young 'Valencia' orange trees. Proc. Fla. State Hort. Soc. 82:1-7.

Calvert, D.V. 1975. Leaching nutrients and pesticides from the soil profile. p. 77-84. In: J.W. Sauls, L.K. Jackson, and J. Soule (eds.). Proc. Second Int. Citrus Short Course -- Water Relations. Univ. of Fla., Gainesville.

Calvert, D.V. and H.T. Phung. 1971. Nitrate-nitrogen movement into drainage lines under different soil management systems. Proc. Soil Crop Sci. Soc. Fla. 31:229-232.

Calvert, D.V. and H.J. Reitz. 1964. Effects of rates and frequency of fertilizer applications on yield and quality of Valencia oranges in the Indian River Area. Proc. Fla. State Hort. Soc. 77:36-40.

Camacho-B., S.E. 1977. Some aspects of the stomatal behavior of citrus. Proc. Int. Soc. Citric. 1:66-69.

Camacho-B., S.E., A.E. Hall, M.R. Kaufmann. 1974. Efficiency and regulation of water transport in some woody and herbaceous species. Plant Physiol. 54:169-172.

Cameron, S.H. 1939. Quantitative relationships between leaf, branch, and root systems of the Valencia orange tree. Proc. Amer. Soc. Hort. Sci. 37:125-126.

Cameron, S.H. and D. Appleman. 1933. The distribution of total nitrogen in the orange tree. Proc. Amer. Soc. Hort. Sci. 30:341-348.

Cameron, S.H. and O.C. Compton. 1945. Nitrogen in bearing orange trees. Proc. Amer. Soc. Hort. Sci. 46:60-68.

Camp, A.F. 1943. A resume of feeding and spraying citrus trees from a nutritional viewpoint. Proc. Fla. State Hort. Soc. 56:60-79.

Carlisle, V.W., F. Sodek, M.E. Collins, L.C. Hammond, and W.G. Harris. 1988. Characterization data for selected Florida soils. Soil Science Research Report Number 88-1. Univ. of Fla., Gainesville.

Castle, W.S. 1978. Citrus root systems: their structure, function, growth, and relationship to tree performance. p. 62-69. Proc. Int. Soc. Citric.

Castle, W.S. 1987. Containers for seedlings and greenhouse liners. p. 38-40. In: J.J. Ferguson (ed.). Proc. of a Citrus Short Course on Citrus Propagation and Nursery Management. Univ. of Fla., Gainesville.

Castle, W.S., W.G. Adams, and R.L. Dilley. 1979. An indoor container system for producing citrus nursery trees in one year from seed. Proc. Fla. State Hort. Soc. 92:3-7.

Chapman, H.D. 1951. Reasons for high nitrogen requirements of citrus in California. Calif. Citrog. 36:223,250-253.

Chapman, H.D., G.F. Leibig, D.S. Rayner. 1949. A lysimeter investigation of nitrogen gains and losses under various systems of covercroppipng and fertilization, and a discussion of error sources. Hilgardia 19:57-128.

Clark, R.N. and E.A. Hiler. 1973. Plant measurements as indicators of crop water deficit. Crop Sci. 13:466-469.

Clarkson, D.J. and J.B. Hanson. 1980. The mineral nutrition of higher plants. Annu. Rev. Plant Physiol. 31:239-298.

Cock, J.H., M.C.M. Porto, and M.A. El-Sharkawy. 1985. Water use efficiency of cassave. III. Influence of air humidity and water stress on gas exchange of field grown cassava. Crop Sci. 25:265-272.

Cohen, S. and Y. Cohen. 1983. Field studies of leaf conductance response to environmental variables in citrus. J. Applied Ecol. 20:561-570.

Cohen, Y., S. Moreshet, and M. Fuchs. 1985. Change in transpiration rate of mature citrus trees in response to a reduction of wetted soil volume. Acta. Hort. 171:45-50.

Cohen, Y., S. Moreshet, and M. Fuchs. 1987. Changes in hydraulic conductance of citrus trees following a reduction in wetted soil volume. Plant, Cell, and Environment 10:53-57.

Cole, P.J. and A.M. Alston. 1974. Effect of transient dehydration on absorption of chloride by wheat roots. Plant Soil 40:243-247.

Cole, P.J. and M.R. Till. 1974. Response of mature citrus trees on deep sandy soil to drip irrigation. p. 521-526. Proc. Second Int. Drip Irrigation Congress. San Diego, CA.

Collatz, G.J. 1977. Influence of certain environmental factors on photosynthesis and photorespiration in Simmondsia chinensis. Planta 134:127-132.

Collison, S.E. 1919. Citrus fertilizer experiments. Univ. of Fla. Agric. Expt. Sta. Bull. 154.

Cooper, W.C., A. Peynado, J.R. Furr, R.H. Hilgeman, G.A. Cahoon, and S.B. Boswell. 1963. Tree growth and fruit quality of 'Valencia' oranges in relation to climate. Proc. Amer. Soc. Hort. Sci. 82:180-192.

Cooper, W.C., R.H. Young, and W.H. Henry. 1969. Effect of growth regulators on bud growth and dormancy in citrus as influenced by season of year and climate. Proc. First Int. Citrus Symp. 1:301-314.

Costello, L. and J.L. Paul. 1975. Moisture relations in transplanted container plants. HortSci. 10:371-372.

Cowan, I.R. 1977. Stomatal behaviour and environment. Adv. Bot. Res. 4:117-228.

Cox, R.C., P.J. Smith, and T.A. Mansfield. 1985. The significance of natural and synthetic auxins in the control of stomatal movements. Acta. Hort. 171:247-254.

Crider, F.J. 1927. Root studies of citrus trees with practical applications. Citrus Leaves 7:1-3, 27-30.

Davies, F.S. and A.N. Lakso. 1978. Water relations in apple seedlings: changes in water potential components, abscisic acid levels and stomatal conductances under irrigated and non-irrigated conditions. J. Amer. Soc. Hort. Soc. 103:310-313.

Davies, F.S. and A.N. Lakso. 1979. Diurnal and seasonal changes in leaf water potential components and elastic properties in response to water stress in apple trees. Physiol. Plant. 46:109-114.

Davies, W.J., J. Metcalfe, T.A. Lodge, and A.R. da Costa. 1986. Plant growth substances and the regulation of growth under drought. Aust. J. Plant Physiol. 13:105-125.

Davies, W.J., J.A. Wilson, R.E. Sharp, and O. Osonubi. 1981. Control of stomatal behaviour in water-stressed plants. p. 163-185. In: P.G. Jarvis and T.A. Mansfield (eds.). Stomatal physiology. Cambridge Univ. Press, London.

De Barreda, D.G., F. Legaz, E. Primo, E. Lorenzo, R. Ibanez, and V. Torres. 1984. Irrigation of young W. navel cv. Frost trees. Proc. Int. Soc. Citric. 1:121-124.

DeBusk, E.F. 1928. Irrigation of citrus trees. Proc. Fla. State Hort. Soc. 41:193-198.

DeBusk, E.F. 1933. The correlation of daily rainfall and soil moisture with citrus yield and size of fruit. Proc. Fla. State Hort. Soc. 46:44-47.

Division of Plant Industry. 1986. Inventory of commercial citrus acreage. Florida Crop and Livestock Reporting Service, Orlando, Fla.

Doley, D. 1981. Tropical and subtropical forests and woodlands. p. 209-305. In: T.T. Kozlowski (ed.). Water deficits and plant growth. Vol. VI. Academic Press, Inc., London.

Dunnett, C.W. 1964. New tables for multiple comparisons with a control. Biometrics 20:482-491.

Edwards, M. and H. Meidner. 1978. Stomatal responses to humidity and the water potentials of epidermal and mesophyll tissue. J. Exp. Bot. 29:771-780.

Elam, W.W., J.D. Hodges, and D.J. Moorhead. 1981. Production of containerized southern red oaks and their performance after out planting. p. 69-76. In: R.W. Guldin and J.P. Barnett (eds.). Proc. southern containerized forest tree seedling conference. Savannah, GA.

Erickson, L.C. 1968. The general physiology of citrus. p. 86-122. In: W. Reuther, L.D. Batchelor, and H.J. Webber (eds.). The Citrus Industry, Vol. 2. Univ. of Calif. Press, Berkeley.

Fairchild, G.F. and M.G. Brown. 1986. Economic factors affecting Florida fresh citrus. Proc. Fla. State Hort. Soc. 99:78-81.

Fanjul, L. and H.G. Jones. 1982. Rapid stomatal responses to humidity. Planta 154:135-138.

Farquhar, G.D. 1978. Feedforward responses of stomata to humidity. Aust. J. Plant Physiol. 5:787-800.

Farquhar, G.D., E.D. Schulze, and M. Kuppers. 1980. Responses to humidity by stomata of Nicotiana glauca L. and Corylus avellana L. are consistent with the optimization of carbon dioxide uptake with respect to water loss. Aust. J. Plant Physiol. 7:315-327.

Farquhar, G.D. and T.D. Sharkey. 1982. Stomatal conductance and photosynthesis. Annu. Rev. Plant Physiol. 33:317-345.

Fereres, E., G. Cruz-Romero, G.J. Hoffman, and S.L. Rawlins. 1979. Recovery of orange trees following some water stress. J. Appl. Ecol. 16:833-842.

Frensch, J. and E.D. Schulze. 1987. Methods of determining gradients in tissue water relation parameters and their effect on stomatal behavior. Proc. Int. conf. on measurement of soil and plant water status. Vol 2:147-154. Logan, Utah.

Ford, H.W. 1964. The citrus root system in sandy soils of central Florida. p. 273-275. The Punjab Fruit J., Citrus Section. India.

Fucik, J.E. 1974. Potting mixes and fertilizer tablets for container-grown citrus. J. Rio Grande Valley Hort. Soc. 28: 143-148.

Gardner, F.E. and G.E. Horanic. 1959. Relation of citrus nursery tree size from 1/2 to 7/8 inches to ultimate size and production. Proc. Fla. State Hort. Soc. 72:102-105.

Gates, C.T. 1955. The response of the young tomato plant to a brief period of water shortage. I. The whole plant and its principle parts. Aust. J. Biol. Sci. 8:196-214.

Genty, B., J.M. Briantais, and J.B.V. Da Silva. 1987. Effects of drought on primary photosynthetic processes of cotton leaves. Plant Physiol. 83:360-364.

Gerber, J.F., A.H. Krezdorn, J.F. Bartholic, J.R. Conner, H.J. Reitz, R.C.J. Koo, D.S. Harrison, E.T. Smerdon, J.G. Georg, L.D. Harris, and J.T. Bradley. 1973. Water needs of Florida citrus. Proc. Fla. State Hort. Soc. 86:61-64.

Gollan, T., J.B. Passioura, and R. Munns. 1986. Soil water status affects the stomatal conductance of fully turgid wheat and sunflower leaves. Aust. J. Plant Physiol. 13:459-464.

Gollan, T., N.C. Turner, and E.D. Schulze. 1985. The responses of stomata and leaf gas exchange to vapour pressure deficits and soil water content. III. in the sclerophyllous woody species Nerium oleander. Oecologia 65:356-362.

Goode, J.E., K.H. Higgs, and K.J. Hyrycz. 1978. Nitrogen and water effects on the nutrition, growth, crop yield, and fruit quality of orchard grown Cox's Pippin apple trees. J. Hort. Sci. 53:295-306.

Goode, J.E. and K.J. Hyrycz. 1964. The response of Laxton's Superb apple trees to different soil moisture conditions. J. Hort. Sci. 39:254-276.

Goode, J.E. and K.J. Hyrycz. 1970. The response of black currants to different soil moisture conditions and two levels of nitrogenous fertilizer. J. Hort. Sci. 45:379-391.

Grimm, G.R. 1956. Preliminary investigations on dieback of young transplanted citrus trees. Proc. Fla. State Hort. Soc. 69:31-34.

Grimm, G.R. 1957. Factors affecting dieback and growth response of young transplanted citrus trees. Proc. Fla. State Hort. Soc. 70:82-85.

Hagan, R.M., Y. Vaadia, and M.B. Russell. 1959. Interpretation of plant responses to soil moisture regimes. Adv. Agron. 11:77-98.

Hall, A.E., S.E. Camacho-B., and M.R. Kaufmann. 1975. Regulation of water loss by citrus leaves. Physiol. Plant. 33:62-65.

Hameed, M.A., J.B. Reid, and R.N. Rowe. 1987. Root confinement and its effects on the water relations, growth, and assimilate partitioning of tomato (Lycopersicon esculentum Mill.). Ann. Bot. 59:685-692.

Hanson, A.D. and W.D. Hitz. 1982. Metabolic responses of mesophytes to plant water deficits. Annu. Rev. Plant Physiol. 33:163-203.

Harris, F.S. 1914. The effect of soil moisture, plant food, and age on the ratio of tops to roots in plants. J. Amer. Soc. Agron. 6:65-75.

Hatton, T.T. 1949. Studies on the periodic development of roots and shoots in certain citrus species. M.S. Thesis, Univ. of Fla., Gainesville.

Hellum, A.K. 1981. Root egress in lodgepole pine seedlings grown in peat and planted in soil. p. 389-396. In: J.B. Scavatt, C. Glerum, and C.A. Plexman (eds.). Proc. Canadian Containerized Tree Seedling Symp. Toronto, Canada.

Hiatt, H.A. and R.W. Tinus. 1974. Container shape controls root system configuration of Ponderosa pine. p. 194-196. In: R.W. Tinus, W.I. Stein, and W.E. Balmer (eds.). Proc. North Amer. Containerized Forest Tree Seedling Symp. Great Plains Agric. Counc. Publ. No. 68.

Hilgeman, R.H. 1941. Nitrogen uptake by grapefruit trees in the Salt River Valley. Proc. Amer. Soc. Hort. Sci. 39:119-124.

Hilgeman. R.H. 1956. New irrigation plan for orange trees. Calif. Citrog. 41:55.

Hilgeman, R.H. 1966. Effect of climate of Florida and Arizona on grapefruit fruit enlargement and quality; apparent transpiration and internal water stress. Proc. Fla. State Hort. Soc. 79:99-106.

Hilgeman, R.H. 1977. Responses of citrus trees to water stress in Arizona. Proc. Int. Soc. Citric. 1:70-74.

Hilgeman, R.H., W.L. Ehrler, C.E. Everling, and F.O. Sharp. 1969. Apparent transpiration and internal water stress in Valencia oranges as affected by soil water, season, and climate. Proc. First Int. Citrus Symp. 3:1713-1723.

Hilgeman, R.H. and F.O. Sharp. 1970. Response of 'Valencia' orange trees to four soil water schedules during 20 years. J. Amer. Soc. Hort. Sci. 95:739-745.

Hillel, D. 1982. Introduction to soil physics. Academic Press, Inc., London.

Hite, W.A. 1974. Container field performance in the Rockies and Plains. p. 306-309. In: R.W. Tinus, W.E. Stein, and W.E. Balmer (eds.). Proc. North Amer. containerized forest tree seedling symp. Great Plains Agric. Counc. Publ. No. 68.

Hoard, J.W. 1908. Irrigation. Proc. Fla. State Hort. Soc. 21:175-179.

Hoffman, G.J., J.D. Oster, and W.J. Olves. 1982. Evapotranspiration of mature orange trees under drip irrigation in an arid climate. Trans ASAE 25:992-996.

Hsiao, T.C. 1973. Plant responses to water stress. Annu. Rev. Plant Physiol. 24:519-570.

Hsiao, T.C. and E. Acevedo. 1974. Plant responses to water deficits, water-use efficiency, and drought resistance. Agric. Meteorol. 14:59-84.

Hsiao, T.C., E. Acevedo, and D.W. Henderson. 1970. Maize leaf elongation: continuous measurements and close dependence on plant water status. Science 168:590-591.

Huffaker, R.C., T. Radin, G.E. Klainkopf, and E.L. Cox. 1970. Effects of mild water stress on enzymes of nitrate assimilation and enzymes of the carboxylative phase of photosynthesis in barley. Crop Sci. 10:471-474.

Huguet, J.G. 1973. New methods of studying the rooting of perennial plants by means of a spiral trench. Ann. Agron. 24:707-731.

Husain, I. and D. Aspinall. 1970. Water stress and apical morphogenesis in barley. Ann. Bot. 34:393-408.

Hutcheson, C.E. and J.E. Bellizio. 1974. A survey of drip irrigation systems in southwest Florida. Proc. Fla. State Hort. Soc. 87:55-56.

Idso, S.B., R.J. Reginato, D.C. Reicosky, and J.L. Hatfield. 1981. Determining soil-induced plant water potential depressions in alfalfa by means of infrared thermometry. Agron. J. 73:826-830.

Itai, C. and Y. Vaadia. 1965. Kinetin-like activity in root exudate of water-stressed sunflower plants. Physiol. Plant. 18:941-944.

Jackson, L.K. and F.S. Davies. 1984. Mulches and slow-release fertilizers in a citrus young tree care program. Proc. Fla. State Hort. Soc. 97:37-39.

Jackson, L.K. and J.J. Ferguson. 1984. Planting and care of dooryard citrus. Fla. Coop. Ext. Service/Institute of Food and Agric. Sci. Fact Sheet 31-A. Univ. of Fla., Gainesville.

Jackson, L.K. and F.P. Lawrence. 1984. Dooryard citrus. Fla. Coop. Ext. Service/Institute of Food and Agric. Sci. Fact Sheet 13. Univ. of Fla., Gainesville.

Jackson, L.K., W.R. Summerhill, and J.J. Ferguson. 1986. A survey of young citrus tree care practices in Florida. Proc. Fla. State Hort. Soc. 99:44-46.

Jarvis, P.G. and J. Catsky. 1971. General principles of gasometric methods and the main aspects of installation design. p. 49-140. In: Z. Sestak, J. Catsky, and P.G. Jarvis (eds.). Plant photosynthesic production: manual of methods. Junk, The Hague, Netherlands.

Jones, H.G. 1973. Moderate-term water stresses and associated changes in some photosynthetic parameters in cotton. New Phytol. 72:1095-1105.

Jones, H.G., M.T. Luton, K.H. Higgs, and P.J.C. Hamer. 1983. Experimental control of water status in an apple orchard. J. Hort. Sci. 58:301-316.

Kaufmann, M.R. 1968. Water relations of pine seedlings in relation to root and shoot growth. Plant Physiol. 43:281-288.

Kaufmann, M.R. 1977. Citrus -- a case study of environmental effect on plant water relations. Proc. Int. Soc. Citric. 1:57-62.

Kaufmann, M.R. and Y. Levy. 1976. Stomatal response of Citrus jambhiri to water stress and humidity. Physiol. Plant. 38:105-108.

Keck, R.W. and J.S. Boyer. 1974. Chloroplast response to low leaf water potentials. III. Differing inhibition of electron transport and photophosphorylation. Plant Physiol. 53:474-479.

Khairi, M.M.A. and A.E. Hall. 1976a. Temperature and humidity effects on net photosynthesis and transpiration of citrus. Physiol. Plant. 36:29-34.

Khairi, M.M.A. and A.E. Hall. 1976b. Comparative studies of net photosynthesis and transpiration of some citrus species and relatives. Physiol. Plant. 36:35-39.

Khalaf, H.A. 1980. The influence of controlled-release and soluble nitrogen fertilizers on newly transplanted Troyer citrange seedlings [Citrus sinensis (L.) Osbeck X Poncirus trifoliata (L.) Raf.]. M.S. Thesis. Univ. of Fla., Gainesville.

Khalaf, H.A. and R.C.J. Koo. 1983. The use of controlled release nitrogen on container grown citrus seedlings. Citrus Veg. Mag. 46:10,32.

Koo, R.C.J. 1953. A study of soil moisture in relation to absorption and transpiration by citrus. Ph.D. Diss., Univ. of Fla., Gainesville.

Koo, R.C.J. 1963. Effects of frequency of irrigations on yield of orange and grapefruit. Proc. Fla. State Hort. Soc. 76:1-5.

Koo, R.C.J. 1969. Evapotranspiration and soil moisture determination as guides to citrus irrigation. Proc. First Int. Citrus Symp. 3:1725-1730.

Koo, R.C.J. 1975. Water requirements of citrus and response to supplemental irrigation. p. 24-27. In: J.W. Sauls, L.K. Jackson, and J. Soule (eds.). Proc. Second Int. Citrus Short Course - Water Relations.

Koo, R.C.J. 1978. Response of densely planted 'Hamlin' orange on two rootstocks to low volume irrigation. Proc. Fla. State Hort. Soc. 91:8-10.

Koo, R.C.J. 1979. The influence of N,K, and irrigation on tree size and fruit production of 'Valencia' orange. Proc. Fla. State Hort. Soc. 92:10-13.

Koo, R.C.J. 1980. Results of citrus fertigation studies. Proc. Fla. State Hort. Soc. 93:33-36.

Koo, R.C.J. 1985. Response of 'Marsh' grapefruit trees to drip, under tree spray and sprinkler irrigation. Proc. Fla. State Hort. Soc. 98:29-32.

Koo, R.C.J. 1986. Controlled-release sources of nitrogen for bearing citrus. Proc. Fla. State Hort. Soc. 99:46-48.

Koo, R.C.J., C.A. Anderson, I. Stewart, D.P.H. Tucker, D.V. Calvert, and H.K. Wutscher. 1984. Recommended fertilizers and nutritional sprays for citrus. Fla. Agr. Expt. Sta. Bul. 536D.

Koo, R.C.J. and G.T. Hurner, Jr. 1969. Irrigation requirements of citrus grown on Lakeland fine sand. Proc. Fla. State Hort. Soc. 81:69-72.

Koo, R.C.J. and A.A. McCormack. 1965. Effects of irrigation and fertigation on production and quality of 'Dancy' tangerine. Proc. Fla. State Hort. Soc. 78:10-15.

Koo, R.C.J. and R.L. Reese. 1971. The effects of omitting single nutrient elements from fertilizer on growth and performance of 'Pineapple' orange. Proc. Fla. State Hort. Soc. 84:11-16.

Koo, R.C.J. and J.W. Sites. 1955. Results of research and response of citrus to supplemental irrigation. Proc. Soil Sci. Soc. Fla. 15:180-190.

Koo, R.C.J. and D.P.H. Tucker. 1974. Soil moisture distribution in citrus groves under drip irrigation. Proc. Fla. State Hort. Soc. 87:61-65.

Koo, R.C.J., T.W. Young, R.L. Reese, and J.W. Kesterson. 1974. Effects of nitrogen, potassium, and irrigation on yield and quality of lemon. J. Amer. Soc. Hort. Sci. 99:289-291.

Kozlowski, T.T. 1983. Reduction in yield of forest and fruit trees by water and temperature stress. p. 67-88. In: C.D. Raper, Jr. and P.J. Kramer (eds.). Crop reactions to water and temperature stresses in humid, temperate climates. Westview Press, Boulder, Colorado.

Kramer, P.J. 1950. Effects of wilting on the subsequent intake of water by plants. Amer. J. Bot. 37:280-284.

Kramer, P.J. 1983. Water relations of plants. Academic Press, Inc., London.

Kramer, P.J. and T.T. Kozlowski. 1979. Physiology of woody plants. Academic Press, New York.

Kriedemann, P.E. 1968. Some photosynthetic characteristics of citrus leaves. Aust. J. Biol. Sci. 21:895-905.

Kriedemann, P.E. 1971. Photosynthesis and transpiration as a function of gaseous diffusive resistances in orange leaves. Physiol. Plant. 24:218-225.

Kriedemann, P.E. and H.D. Barrs. 1981. Citrus orchards. p. 325-417. In: T.T. Kozlowski (ed.). Water deficits and plant growth. Vol. VI. Academic Press, Inc. London.

Krishnamurthi, S., G.S. Randhawa, and P.C. Sivaraman Nair. 1960. Growth studies in some citrus species under sub-tropical conditions. Indian J. Hort. 17:171-184.

Lange, O.L., R. Losch, E.D. Schulze, and L. Kappen. 1971. Responses of stomata to changes in humidity. Planta 100:76-86.

Lavender, D.P. and B.D. Cleary. 1974. Coniferous seedling production techniques to improve seedling establishment. p. 177-180. In: R.W. Tinus, W.I. Stein, and W.E. Balmer (eds.). Proc. North Amer. containerized forest tree seedling symp. Great Plains Agric. Counc. Publ. No. 68.

Lawlor, D.W. 1979. Effects of water and heat stress on carbon metabolism of plants with C_3 and C_4 photosynthesis. p. 303-326. In: H. Mussell and R.C. Staples (eds.). Stress physiology in crop plants. John Wiley & Sons, New York.

Layne, R.E.C., C.S. Tan, and R.L. Perry. 1986. Characterization of peach roots in Fox sand as influenced by sprinkler irrigation and tree density. J. Amer. Soc. Hort. Sci. 111:670-677.

Legaz, F.R., R. Ibanez, P.G. de Barreda, and E. Millo- Primo. 1981. Influence of irrigation and fertilization on productivity of 'Navelate' sweet orange. Proc. Int. Soc. Citric. 2:591-595.

Lenz, F. 1969. Effects of day length and temperature on the vegetative and reproductive growth of 'Washington Navel' orange. Proc. First Int. Citrus Symp. 1:333-338.

Leonard, C.D., I. Stewart, and I.W. Wander. 1961. A comparison of ten nitrogen sources for Valencia oranges. Proc. Fla. State Hort. Soc. 74:79-86.

Lesham, B. 1965. The annual activity of intermediary roots of the Aleppo pine. Forest Sci. 11:291-298.

Levin, I., R. Assaf, and B. Bravdo. 1980. Irrigation, water status and nutrient uptake in an apple orchard. p. 255-263. In: D. Atkinson, J.E. Jackson, R.O. Sharples, and W.M. Waller (eds.). Mineral nutrition of fruit trees. Butterworths, London.

Levy, Y. 1980. Effect of evaporative demand on water relations of Citrus limon. Ann. Bot. 46:695-700.

Levy, Y., H. Bielorai, and J. Shalhevet. 1978. Long-term effects of different irrigation regimes on grapefruit tree development and yield. J. Amer. Soc. Hort. Sci. 103:680-683.

Levy, Y. and J.P. Syvertsen. 1981. Water relations of citrus in climates with different evaporative demands. p. 501-503. Proc. Int. Soc. Citric.

Levy, Y., J.P. Syvertsen, and S. Nemec. 1983. Effect of drought stress and VAM on citrus transpiration and hydraulic conductivity of roots. New Phytol. 93:61-66.

Leyden, R.F. 1975a. Comparison of three irrigation systems for young citrus trees. J. Rio Grande Valley Hort. Soc. 29:25-29.

Leyden, R.F. 1975b. Drip irrigation on bearing citrus trees. J. Rio Grande Valley Hort. Soc. 29:31-36.

Leyden, R.F. and L.W. Timmer. 1978. Container production of citrus nursery stock and its performance compared to field stock. J. Rio Grande Valley Hort. Soc. 32:43-53.

Lorenzo-Minguez, P., R. Ceulemanns, R. Gabriels, I. Impens, and O. Verdonck. 1985. Effect of short-term water stress on leaf gas exchange processes and plant water potential in schefflera. HortSci. 20:932-934.

Losch, R. and Tenhunen. 1981. Stomatal responses to humidity: phenomenon and mechanism. p. 137-162. In: P.G. Jarvis and T.A. Mansfield (eds.). Stomatal physiology. Cambridge Univ. Press., Cambridge.

Ludlow, M.M. 1976. Ecophysiology of C_4 grasses. p. 364-386. In: O.L. Lange, C. Kappen, and E.D. Schulze. (eds.). Water and Plant Life. Ecological Studies, Vol. 19. Springer-Verlag, Berlin.

Ludlow, M.M. and K. Ibaraki. 1979. Stomatal control of water loss in siratro (Macroptilium artropurpureum (D.C.) Urb.), a tropical pasture legume. Ann. Bot. 43:639-647.

Mansfield, T.A. and W.J. Davies. 1985. Mechanisms for leaf control of gas exchange. BioScience 35:158-164.

Mantell, A. 1977. Water use efficiency of citrus: room for improvement. Proc. Int. Soc. Citric. 1:74-79.

Marsh, A.W. 1973. Irrigation. p. 230-279. In: W. Reuther (ed.). The Citrus Industry, Vol. 3. Univ. Calif. Press, Berkeley.

Maxwell, N.P. and R.E. Rouse. 1980. Growth and yield comparison of six-year-old container- and field-grown red grapefruit trees. J. Rio Grande Valley Hort. Soc. 34:71-73.

Maxwell, N.P. and R.E. Rouse. 1984. Growth and yield comparison of ten-year-old red grapefruit trees from field- and container-grown nursery stock. J. Rio Grande Valley Hort. Soc. 37:71-73.

Maynard, D.N. and O.A. Lorenz. 1979. Controlled-release fertilizers for horticultural crops. p. 79-140. In: J. Janick (ed.). Horticultural Reviews Vol 1 AVI, Westport, Conn.

Mederski, H.J., R.B. Curry, and L.H. Chen. 1975. Effects of irradiance and leaf water deficit on net carbon dioxide assimilation and mesophyll transport resistance. Plant Physiol. 55:594-597.

Mendel, K. 1969. The influence of temperature and light on the vegetative development of citrus trees. Proc. First Int. Citrus Symp. 1:259-265.

Mengel, K. and E.A. Kirkby. 1982. Principles of plant nutrition, 3rd ed. Int. Potash Institute. Bern, Switzerland.

Menzel, C.M., D.R. Simpson, and A.J. Dowling. 1986. Water relations in passionfruit: effect of moisture stress on growth, flowering, and nutrient uptake. Scientia Hort. 29:239-249.

Miller, L.N. 1965. Changes in radiosensitivity of pine seedlings subjected to water stress during chronic gamma irradiation. Health Physics 11:1653-1662.

Minessy, F.A., M.A. Barakat, and E.M. El-Azab. 1971. Effect of some soil properties on root and top growth and mineral content of Washington navel orange and Balady mandarin. Plant and Soil 34:1-15.

Monson, R.K., M.A. Stidham, G.J. Williams III, G.E. Edwards, and E.G. Uribe. 1982. Temperature dependence of photosynthesis in Agropyron smithii Rydb. I. Factors affecting net CO_2 uptake in intact leaves and contribution from ribulose-1,5-bisphosphate carboxylase measured in vivo and in vitro. Plant Physiol. 69:921-928.

Moore, P.W. 1966. Propagation and growing citrus nursery trees in containers. Proc. Int. Plant Prop. Soc. 16:54-62.

Moreshet, S., Y. Cohen, and M. Fuchs. 1983. Responses of maature 'Shamouti' orange trees to irrigation of different soil volumes at similar levels of available water. Irrig. Sci. 3:223-236.

Nelms, L.R. and L.A. Spomer. 1983. Water retention of container soils transplanted into ground beds. HortSci. 18:863-866.

Nir, I. and Poljakoff-Mayber. 1967. Effects of water stress on the photochemical activity of chloroplasts. Nature 213:418-419.

Oertli, J.J. 1980. Controlled-release fertilizers. Fertilizer Research 1:103-123.

Ono, S. and K. Hirose. 1984. Some photosynthetic characteristics of satsuma Mandarins. Proc. Int. Soc. Citric. 1:6-11.

Osonubi, O. 1985. Responses of cowpeas (Vigna unguiculata (L.) Walp.) to progressive soil drought. Oecologia 66:554-557.

O'Toole, J.C., R.K. Crookston, K.J. Treharne, and J.L. Ozbun. 1976. Mesophyll resistance and carboxylase activity. A comparison under water stress conditions. Plant Physiol. 57:465-468.

Pearcy, R.W. 1983. Physiological consequences of cellular water deficits: nonstomatal inhibition of photosynthesis by water stress. p. 277-287. In: H.M. Taylor, W.R. Jordan, and T.R. Sinclair (eds.). Limitations to efficient water use in crop production. ASA-CSSA-SSSA. Madison, Wisc.

Pellegrino, A., J. Moon, and A. Mattias. 1987. Effect of soil moisture stress on the gas exchange characteristics and mesophyll conductance of 'Cabernet Sauvignon' grape. Proc. Int. conf. on measurement of soil and plant water status. Vol. 2:121-122. Logan, Utah.

Piringer, A.A., R.J. Downs, and H.A. Borthwick. 1961. Effects of photoperiod and kind of supplemental light on the growth of 3 species of Citrus and Poncirus trifoliata. Proc. Amer. Soc. Hort. Sci. 77:202-210.

Platt, R.G. and K.W. Opitz. 1973. Propagation of citrus. p. 147. In: W. Reuther (ed.). The Citrus Industry, Vol. 3. Univ. of Calif. Press, Berkeley.

Ponder, H.G. and A.L. Kenworthy. 1976. Trickle irrigation of shade trees growing in the nursery: II. Influence on root distribution. J. Amer. Soc. Hort. Sci. 101:104-107.

Radin, J.W. and R.C. Ackerson. 1981. Water relations of cotton plants under nitrogen deficiency. III. Stomatal conductance, photosynthesis, and abscisic acid accumulation during drought. Plant Physiol. 67:115-119.

Ramos, C. and M.R. Kaufmann. 1979. Hydraulic resistance of rough lemon roots. Physiol. Plant. 45:311-314.

Raschke, K. 1975. Stomatal action. Annu. Rev. Plant Physiol. 26:309-340.

Raschke, K., M. Pierce, and C.C. Popiela. 1976. Abscisic acid content and stomatal sensitivity to CO_2 in leaves of Xanthium strumarium L. after pretreatments in warm and cold growth chambers. Plant Physiol. 57:115-121.

Rasmussen, G.K. and P.F. Smith. 1961. Evaluation of fertilizer practices for young orange trees. Proc. Fla. State Hort. Soc. 74:90-95.

Rasmussen, G.K. and P.F. Smith. 1962. Evaluation of fertilizer practices for young orange trees. The Citrus Industry 43(9):16-19.

Rathwell, P.J. and R.F. Leyden. 1976. Cost comparison of drip and flood irrigation systems. J. Rio Grande Valley Hort. Soc. 30:79-86.

Redshaw, A.J. and H. Meidner. 1972. Effects of water stress on the resistance to uptake of carbon dioxide in tobacco. J. Exp. Bot. 23:229-240.

Reed, H.S. and D.T. MacDougal. 1937. Periodicity in growth of the orange tree. Growth 1:371-373.

Reese, R.L. & R.C.J. Koo. 1976. Influence of fertility and irrigation treatments on yield and leaf and analyses of 'Temple' orange. Proc. Fla. State Hort. Soc. 89:46-48.

Reicosky, D.C., R.B. Campbell, and C.W. Doty. 1976. Corn plant water stress as influenced by chiseling, irrigation, and water table depth. Agron. J. 68:499-503.

Reitz, H.J. 1956. Timing fertilization of citrus in the Indian River area. Proc. Fla. State Hort. Soc. 69:58-64.

Reitz, H.J., L.G. Albrigo, L.H. Allen, Jr., J.F. Bartholic, D.V. Calvert, H.W. Ford, J.F. Gerber, L.C. Hammond, D.S. Harrison, R.C.J. Koo, R.S. Mansell, J.M. Myers, J.S. Rogers, and D.P.H. Tucker. 1978. Water requirements for citrus. Institute of Food and Agric. Sci. WRC-4. Univ. of Fla., Gainesville.

Reitz, H.J. and R.C.J. Koo. 1959. Effects of nitrogen and potassium fertilization on yield and fruit quality of Valencia oranges on calcareous soil. Proc. Fla. State Hort. Soc. 72:12-16.

Reuther, W. 1973. Climate and citrus behavior. p. 280-337. In: W. Reuther (ed.). The Citrus Industry, Vol. 3. Univ. of Calif. Press, Berkeley.

Reuther, W. and P.F. Smith. 1954. Effect of method of timing nitrogen fertilization on yield and quality of oranges. Proc. Fla. State Hort. Soc. 67:20-26.

Richards, D. and B. Cockroft. 1975. The effect of soil water on root production of peach trees in summer. Austral. J. Agr. Res. 26:173-180.

Richards, S.J., M.K. Harjung, J.E. Warnecke, and W.H. Hillis. 1967. Unique procedures employed in growing lemon trees. Calif. Citrog. 48:96-99.

Rieger, M., F.S. Davies, L.K. Jackson. 1986. Microsprinkler irrigation and microclimate of young orange trees during freeze conditions. HortSci. 21:1372-1374.

Rodgers, W.S. 1939. Root studies. VIII. Apple root growth in relation to rootstock, soil, seasonal and climatic factors. J. Pomol. Hort. Sci. 17:99-130.

Rodney, D.R., R.L. Roth, and B.R. Gardner. 1977. Citrus responses to irrigation methods. Proc. Int. Soc. Citric. 1:106-110.

Rogers, J.S., L.H. Allen, Jr., and D.V. Calvert. 1983. Evapotranspiration from a humid-region developing citrus grove with grass cover. Trans. ASAE 26:1778-1783,1792.

Rogers, J.S. and J.F. Bartholic. 1975. Estimated evapotranspiration and irrigation requirements for citrus. Proc. Soil and Crop Sci. Soc. Fla. 35:111-117.

Rook, D.A. 1973. Conditioning radiata pine seedlings to transplanting by restricting watering. New Zealand J. For. Sci. 3:54-59.

Roth, R.L., B.R. Gardner, and D.R. Rodney. 1981. Conversion of grapefruit to trickle irrigation. Citrog. 66:145-147.

Roth, R.L., D.R. Rodney, and B.R. Gardner. 1974. Comparison of irrigation methods, rootstocks, and fertilizer elements on Valencia orange trees. p. 103-108. Proc. Second Int. Drip Irrig. Congress.

Ruggiero, C. and R. Andiloro. 1985. Response of orange and young apricot trees to different water regimes. Acta Hort. 171:427-440.

Russell, R.S. 1977. Plant root systems: their function and interaction with the soil. McGraw-Hill, London.

Sauer, M.R. 1951. Growth of orange shoots. Aust. J. Agric. Res. 2:105-117.

Savage, Z. 1951. Results shown by production records on irrigated and nonirrigated groves. Citrus Industry 32(9):5,12, 17-18.

Savage, Z. 1952. Does grove irrigation pay? yes or no. Citrus Industry 33(9):4,13-15.

Savage, E.M., W.C. Cooper, and R.B. Piper. 1945. Root systems of various citrus rootstocks. Proc. Fla. State Hort. Soc. 58:44-48.

Schneider, H. 1968. The anatomy of citrus. p. 1-22. In: W. Reuther, L.D. Batchelor, and H.J. Webber (eds.). The Citrus Industry, Vol. 2. Univ. of Calif. Press, Berkleley.

Scholander, P.F., H.T. Hammel, E.D. Bradstreet, and E.A. Hemmingsen. 1965. Sap pressure in vascular plants. Science 148:339-346.

Schroeder, C.A. 1951. Shoot growth in citrus. Calif. Citrog. 37:16,19,20.

Shackel, K.A. and E. Brinckmann. 1985. In situ measurement of epidermal cell turgor, leaf water potential, and gas exchange in Tradescantia virginiana L.. Plant Physiol. 78:66-70.

Sharkey, T.D. 1984. Transpiration induced changes in the photosynthetic capacity of leaves. Planta 160:143-150.

Sharkey, T.D. and M.R. Badger. 1982. Effects of water stress on photosynthetic electron transport, photophosphorylation, and metabolite levels of Xanthium strumarium mesophyll cells. Planta 156:199-206.

Sinclair, T.R. and L.H. Allen, Jr. 1982. Carbon dioxide and water vapour exchange of leaves on field-grown citrus trees. J. Exp. Bot. 33:1166-1175.

Sinclair, W.B. 1984. The biochemistry and physiology of the lemon and other citrus fruits. Univ. of Calif. Pub. 3306. Oakland, CA.

Sites, J.W. 1949. Present status of organic versus inorganic nitrogen as related to yield and fruit quality. Proc. Fla. State Hort. Soc. 62:65-71.

Sites, J.W., H.J. Reitz, and J.E. Deszyck. 1951. Some results of irrigation research with Florida citrus. Proc. Fla. State Hort. Soc. 64:71-79.

Sites, J.W., I.W. Wander, and J.E. Deszyck. 1953. The effects of fertilization timing and rate of application on fruit quality and production of Hamlin oranges. Proc. Fla. State Hort. Soc. 66:54-62.

Sites, J.W., I.W. Wander, and J.E. Deszyck. 1961. The rate and timing of nitrogen for grapefruit on Lakeland fine sand. Proc. Fla. State Hort. Soc. 74:53-57.

Slatyer, R.O. 1967. Plant-water relations. Academic Press. New York.

Slatyer, R.O. 1969. Physiological significance of internal water relations to crop yield. p. 53-83. In: J.D. Eastin, F.A. Haskins, L.Y. Sullivan, C.H.M. Van Bavel (eds.). Physiological aspects of crop yield. ASA-CSSA, Madison, WI.

Smajstrla, A.G. and R.C.J. Koo. 1984. Effects of trickle irrigation methods and amounts of water applied on citrus yields. Proc. Fla. State Hort. Soc. 97:3-7.

Smajstrla, A.G. and R.C.J. Koo. 1985. Effects of trickle irrigation methods and amounts of water applied on citrus yields. Citrus Industry 66(1):20-30,32,70.

Smajstrla, A.G., L.R. Parsons, K. Aribi, and G. Velledis. 1985. Responses of young citrus trees to irrigation. Proc. Fla. State Hort. Soc. 98:25-28.

Smith, P.F. 1963. Nitrogen in citrus fertilization. Citrus Industry 44(1):9-10.

Smith, P.F. 1970. A comparison of nitrogen sources and rates on old, high yielding Valencia orange trees in Florida. Proc. Amer. Soc. Hort. Sci. 95:15-17.

Snaith, P.J. and T.A. Mansfield. 1982. Control of the CO_2 responses of stomata by indol-3ylacetic acid and abscisic acid. J. Exp. Bot. 33:360-365.

Sojka, R.E. and D.L. Karlen. 1984. Measurement variability in soybean water status and soil-nutrient extraction in a row spacing study in the U.S. Southeastern coastal plain. Commun. in Soil Sci. Plant Anal. 15:1111-1134.

Staebner, F.E. 1919. Irrigation as a grove practice. Proc. Fla. State Hort. Soc. 32:51-52.

Stanley, F.W. 1913. Irrigation of citrus groves. Proc. Fla. State Hort. Soc. 26:159-162.

Stanley, F.W. 1914. The construction of an efficient irrigation plant. Proc. Fla. State Hort. Soc. 27:128-131.

Stanley, F.W. 1916. Need for irrigation in Florida citrus groves. Proc. Fla. State Hort. Soc. 29:71-75.

Stark, J.C. and J.L. Wright. 1985. Relationship between foliage temperature and water stress in potatoes. Amer. Potato J. 62:57-68.

Stevens, H.B. 1909. Irrigation. Proc. Fla. State Hort. Soc. 22:54-56.

Stewart, I., C.D. Leonard, and I.W. Wander. 1961. Comparison of nitrogen rates and sources for Pineapple oranges. Proc. Fla. State Hort. Soc. 74:75-79.

Stidham, M.A., E.G. Uribe, G.J. Williams III. 1982. Temperature dependence of photosynthesis in Agropyron smithii Rydb. II. Contribution from electron transport and photophosphorylation. Plant Physiol. 69:929-934.

Syvertsen, J.P. 1982. Minimum leaf water potential and stomatal closure in citrus leaves of different ages. Ann. Bot. 49:827-834.

Syvertsen, J.P. and J.H. Graham. 1985. Hydraulic conductivity of roots, mineral nutrition, and leaf gas exchange of citrus rootstocks. J. Amer. Soc. Hort. Sci. 110:865-869.

Syvertsen, J.P. and Y. Levy. 1982. Diurnal changes in citrus leaf thickness, leaf water potential, and leaf to air temperature difference. J. Exp. Bot. 33:783-789.

Syvertsen, J.P., M.L. Smith, Jr., and J.C. Allen. 1981. Growth rates and water relations of citrus leaf flushes. Ann. Bot. 47:97-105.

Terman, G.L. and S.E. Allen. 1970. Leaching of soluble and slow-release N and K fertilizers from Lakeland sand under grass and fallow. Proc. Soil and Crop Sci. Soc. Fla. 30:130-140.

Thompson, I.R., L.H. Stolzy, and O.C. Taylor. 1965. Effect of soil suction, relative humidity and temperature on apparent photosynthesis and transpiration of rough lemon (Citrus jambhiri). Proc. Amer. Soc. Hort. Sci. 87:168-175.

Till, M.R. and J.B. Cox. 1965. A guide to cultural practices for young citrus trees. J. of Agr. South Australia Dept. Agr. 68:232-233.

Timmis, R. 1974. Effect of nutrient stress on growth, bud set, and hardiness in Douglas-Fir seedlings. p. 187-193. In: R.W. Tinus, W.E. Stein, and W.E. Balmer (eds.). Proc. North Amer. Containerized Forest Tree Seedling Symp. Great Plains Agric. Counc. Publ. No. 68.

Tinus, R.W. 1974. Characteristics of seedlings with high survival potential. p. 276-281. In: R.W. Tinus, W.E. Stein, and W.E. Balmer (eds.). Proc. North Amer. Containerized Forest Tree Seedling Symp. Great Plains Agric. Counc. Publ. No. 68.

Tinus, R.W. and P.W. Owston. 1984. Physiology research made forestation with contain-grown seedlings successful. p. 143-155. In: M.L. Duryea and G.N. Brown (eds.). Seedling physiology and reforestation success. Dr. W. Junk Publishers. Dordrecht/Boston/London.

Turner, N.C. 1979. Drought resistance and adaptation to water deficits in crop plants. p. 343-372. In: H. Mussel and R.C. Staples (eds.). Stress physiology in crop plants. Wiley, New York.

Turner, N.C. 1986. Crop water deficits: a decade of progress. Adv. Agron. 39:1-51.

Turner, N.C. and P.J. Kramer. 1980. Adaptation of plants to water and high temperature stress. Wiley, New York.

Turner, N.C., E.D. Schulze, and T. Gollan. 1985. The responses of stomata and leaf gas exchange to vapour pressure deficits and soil water content. II. In the mesophytic herbaceous species Helianthus annuus. Oecologia 65:348-355.

Turner, T.U. 1922. Studies of the mechanism of the physiological effects of certain mineral salts in altering the ratio of top growth to root growth in seed plants. Amer. J. Bot. 9:427-445.

Van Eerden, E. and J.T. Arnott. 1974. Root growth of container-grown stock after planting. p. 393-397. In: R.W. Tinus, W.E. Stein, and W.E. Balmer (eds.). Proc. North Amer. Containerized Forest Tree Seedling Symp. Great Plains Agric. Counc. Publ. No. 68.

Van Noort, G. 1969. Determining the potential production of citrus trees in a given environment. Proc. First Int. Citrus Symp. 1:345-350.

Vinokur, R.L. 1957. Influence of temperature of the root environment on root activity, transpiration, and photosynthesis of leaves of lemon. Sov. Plant Physiol. 4:268-273.

Volk, G.M. 1959. Volatile loss of ammonia following surface application of urea to turf or bare soils. Agron. J. 51: 746-749.

Von Caemmerer, S. and G.D. Farquhar. 1981. Some relationships between the biochemistry of photosynthesis and the gas exchange of leaves. Planta 153:376-387.

Wahhab, A., M.S. Randhawa, and S.Q. Alam. 1957. Loss of ammonia from ammonium sulfate under different conditions when applied to soil. Soil Sci. 88:249-255.

Wallace, A. 1954. Ammonium and nitrate nitrogen absorption by citrus. Soil Sci. 78:89-94.

Wallace, A., M.H. Kimball, R.T. Mueller, and H.V. Welch. 1952. Influence of nitrogen fertilizers on orange trees and on the soil in the coastal zone of southern California. Proc. Amer. Soc. Hort. Sci. 59:22-30.

Wallace, A. and R.T. Mueller. 1957. Ammonium and nitrate absorption from sand culture by rough lemon cuttings. Proc. Amer. Soc. Hort. Sci. 69:183-188.

Warneke, J.E. P.W. Moore, and S.J. Richards. 1975. Effect of container size and growing medium on citrus trees. The Plant Propagator 21(2):6-8.

Warner, R.M., Z. Worku, and J.A. Silva. 1979. Effects of photoperiod on growth responses of citrus rootstocks. J. Amer. Soc. Hort. Sci. 104:232-235.

Waynick, D.D. and S.J. Walker. 1930. Rooting habits of citrus trees. Calif. Citrog. 15:201,238-239.

Webb, W.L. 1981. Relation of starch content to conifer mortality and growth loss after defoliation by the Douglas-fir tussock moth. Forest Sci. 27:224-232.

Webber, H.J. 1932. Variations in citrus seedlings and their relation to rootstock selection. Hilgardia 7:1-79.

Westwood, M.N. 1978. Temperate zone pomology. W.H. Freeman & Co., New York.

Wiegand, C.L. and W.A. Swanson. 1982a. Citrus responses to irrigation: I. Irrigation requirements; daily, monthly, and annual evapotranspiration amounts; and water management recommendations. J. Rio Grande Valley Hort. Soc. 35:73-86.

Wiegand, C.L. and W.A. Swanson. 1982b. Citrus responses to irrigation: III. Tree trunk and canopy growth. J. Rio Grande Valley Hort. Soc. 35:97-107.

Williams, D.A. 1971. A test for differences between treatment means when several dose levels are compared to a zero dose control. Biometrics 27:103-117.

Williams, J.D., H.G. Ponder, and C.H. Gilliam. 1987. Responses of Cornus florida to moisture stress. J. Arboriculture 13:98-101.

Williams, M.B. 1909. Irrigation. Proc. Fla. State Hort. Soc. 22:56-57.

Williams, R.F. and R.E. Shapter. 1955. A comparative study of growth and nutrition in barley and rye as affected by low-water treatment. Aust. J. Biol. Sci. 8:435-466.

Wong, S.C., I.R. Cowan, and G.D. Farquhar. 1979. Stomatal conductance correlates with photosynthetic capacity. Nature 282:424-426.

Yagev, E. and Y. Choresh. 1974. Drip irrigation in citrus orchards. p. 456-461. Proc. Second Int. Drip Irrig. Congress. San Diego, CA.

Young, T.W. 1948. Soil moisture and the citrus tree root system. Proc. Fla. State Hort. Soc. 61:74-79.

Zekri, M. 1984. Citrus water relations and growth under different irrigation treatments. M.S. Thesis. Univ. of Fla., Gainesville.

Ziegler, L.W. 1955a. Irrigation studies with Marsh grapefruit. Ph.D. Diss. Univ. of Fla., Gainesville.

Ziegler, L.W. 1955b. Irrigation studies with Marsh grapefruit on Lakeland fine sand in central Florida. Proc. Fla. State Hort. Soc. 68:39-41.

Ziegler, L.W. and H.S. Wolfe. 1975. Citrus growing in Florida. Univ. Presses. Gainesville, Fla.

BIOGRAPHICAL SKETCH

Thomas Marler was born in Seoul, Korea in February of 1959. After living in Korea, Guam, and Mississippi he graduated from high school in 1977 in Jackson, MS. Tommy attended Mississippi College in Clinton, MS for three semesters prior to becoming a horticulture major at Mississippi State University in Starkville, MS. He received his Bachelor of Science degree in 1982 and Master of Science degree in 1984, and subsequently entered the University of Florida to begin working on a Doctor of Philosophy degree. He will be awarded the Ph.D. degree in 1988 and become the curator of tropical fruit crops at Fairchild Tropical Gardens in Miami, FL.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Frederick S. Davies

Frederick S. Davies, Chair
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

James J. Ferguson

James J. Ferguson
Associate Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Larry K. Jackson

Larry K. Jackson
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Robert C. J. Koo

Robert C. J. Koo
Professor of Horticultural Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Allen G. Smajstrla

Allen G. Smajstrla
Professor of Agricultural Engineering

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1988

Jack L. Fry
Dean, College of Agriculture

Dean, Graduate School